U.S. Fish & Wildlife Service

Water Quality, and Metal and Metalloid Concentrations in Water, Sediment, and Fish Tissues from Innoko National Wildlife Refuge, Alaska, 1995-1997

By Keith A. Mueller and Angela C. Matz

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TECHNICAL REPORT

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EXECUTIVE SUMMARY

This study was conducted by U.S. Fish and Wildlife Service biologists from 1995-1997. The study goals were to determine selected metal and metalloid concentrations in water, sediment, and fish tissues at sites within and upstream of Innoko National Wildlife Refuge; determine the uniqueness of chum and coho salmon populations of Illinois and California creeks by comparison of their genetic characteristics with those from other locations; and determine the histologic baseline conditions of juvenile silver salmon in Illinois Creek. This report focuses on the first objective, determinations of water quality variables, and metals concentrations in water, sediment, and fish. Stream water, sediment, and fish samples were collected from 26 sites: 20 sites on Innoko National Wildlife Refuge and 6 in the upper Little Mud River drainage, in areas associated with the Illinois Creek heap-leach gold mine. Mineral deposits of many types have been located around the Refuge and placer mining for gold has occurred in many of the major and minor drainages that enter the Refuge. Extraction of mineral resources may affect fish and wildlife resources and their habitats within the Refuge.

The circumneutral pH values measured at Innoko Refuge and the upper Little Mud River drainage are typical of interior Alaska streams. Measures of dissolved solids in water, conductivity, hardness and alkalinity show that stream water in Innoko Refuge and the upper Little Mud River are within the range typical of surface waters in interior Alaska. Rain had obvious effects on discharge and water quality in Refuge streams. Turbidity was significantly greater at sites sampled after a rain event in 1996, and values for pH, conductivity, hardness and alkalinity were greater at sites sampled before the rain event. Water quality is not a consistent predictor of metals concentrations, as demonstrated by the changing relationships between metal concentrations and water quality variables associated with the rain event of 1996.

Surface waters in Innoko Refuge and the upper Little Mud River were relatively uncontaminated by metals. For example, no dissolved metals concentrations exceeded the Environmental Protection Agency s Water Quality Criteria (WQC). Most metals concentrations were within the ranges of metals measured at Kanuti, Koyukuk, Nowitna, and Selawik National Wildlife Refuges from various dates within the 1980's and 1990's. Although no samples exceeded the EPA chronic WQC for arsenic (0.15 mg/L), mean total arsenic at the Iditarod River for 1997 and at both sample sites on Illinois Creek (1996 only) (0.0057 mg/L, 0.014 mg/L, and 0.017 mg/L, respectively) exceeded the drinking water standard for the State of Alaska of 0.005 mg/L. Mean dissolved iron concentrations exceeded the chronic WQC of 1.0 mg/L and the Canadian guideline for the protection of freshwater aquatic life of 0.3 mg/L total iron in all Innoko River drainage waters measured except Tolstoi, Illinois, and California creeks. Concentrations of total iron frequently exceeded those that cause mortality in rainbow trout eggs. Concentrations of total lead exceeded the EPA chronic WQC (0.0022 mg/L dissolved lead) in one of three samples at Scandinavian Creek for 1996 (0.0117 mg/L) and Finland Creek for 1997 (0.01 mg/L). Dissolved lead was undetected, however, some exceedances of the chronic WQC could have been missed due to high

analytical limits of detection (LODs) which were greater than the WQC. It is unlikely that lead toxicosis is occurring at Innoko Refuge due to mitigating environmental factors such as low water temperatures, circumneutral pHs, and, for total lead, adherence to particulates. Sites sampled after a rain event and at the Big Mud River had the majority of the six greatest concentrations of aluminum, barium, chromium, copper, iron, manganese, nickel, vanadium, and zinc for 1996 but this was not true of the same groups of sites for 1997.

The six sample sites in the upper Little Mud River drainage accounted for four of the six greatest concentrations of arsenic and zinc in sediment (the fifth for both metals was the Little Mud River at the Refuge boundary), and five of six for lead. Sediment samples from Illinois Creek had the greatest concentrations of lead for all sites. Concentrations of metals in sediment at Innoko Refuge sites were within the range observed at other interior Alaska refuges except for arsenic, cadmium, iron, and manganese, which were greater than at other interior Alaska refuges.

Arctic grayling and northern pike are highly migratory species and assigning the origin of contaminants found in these species is difficult. Concentrations of arsenic in most northern pike muscle samples were within the range of, or less than, geometric means of the National Contaminants Biomonitoring Program (NCBP) (0.33 mg/kg - 0.80 mg/kg dry weight). Concentrations of barium, cadmium, copper, iron, magnesium, manganese, nickel, and selenium in northern pike kidney were in the range of values from the Kanuti, Koyukuk, Nowitna, and Selawik refuges. All northern pike muscle samples but one from 1996 exceeded the greatest geometric mean of the NCBP for mercury and six of nine exceeded the 85th percentile maximum value of 0.76 mg/kg. Mercury concentrations in northern pike kidney were similar to those at Kanuti and Selawik refuges but lower than those at Nowitna Refuge. The mean concentration of mercury from 48 northern pike muscle samples from Kaiyuh Flats (Northern Innoko Refuge) was 1.75 mg/kg (assuming 75% moisture) compared with 1.59 mg/kg from Koyukuk, Nowitna and Northern Innoko refuges in 1995, and 1.82 mg/kg and 2.56 mg/kg from our study for 1996 and 1997, respectively. Mean concentrations of cadmium, copper, nickel, lead, and zinc in Arctic grayling liver from the Tolstoi River were less than or equal to the geometric mean concentrations of Arctic grayling liver from four lakes in Arctic Alaska. One of 19 chinook salmon samples (California Creek) and all 5 silver salmon samples (Illinois Creek) were greater than the 85th percentile range of the NCBP for arsenic.

Boron was detected in 17 of 19 chinook salmon fry in concentrations up to 10.0 mg/kg, but not in silver salmon fry or Arctic grayling, and in only 5 northern pike muscle samples at the LOD of 1.0 mg/kg. We do not know if this is a result of differing conditions in the waterbodies or differing species. Salmonids are very sensitive to selenium contamination. Rainbow trout fry have been shown to have significant mortality when whole-body selenium concentrations exceeded 1 mg/kg. Smoltification and seawater migration have been shown to be impaired when whole-body concentrations of selenium were 2 - 3 mg/kg in juvenile chinook salmon. Chinook salmon fry from California Creek had up to 1.5 mg/kg and silver salmon from Illinois Creek had up to 1.3 mg/kg selenium. Slimy sculpin had greater mean concentrations than chinook salmon and coho salmon for all elements measured except for copper. All 3 slimy sculpin samples had concentrations greater than the 85th percentile range of the NCBP for arsenic.

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INTRODUCTION

Innoko National Wildlife Refuge

Innoko National Wildlife Refuge, located about 255 air miles west of Fairbanks in west-central Alaska, was created by the Alaska National Interest Lands Conservation Act of 1980 (ANILCA). Refuge headquarters are in McGrath, Alaska, approximately 70 air miles east of the Refuge s east boundary. The exterior boundaries of the Refuge encompass approximately 1.5 million hectares, including approximately 1.4 million hectares of Refuge lands (U.S. Fish and Wildlife Service 1987). The Refuge contains approximately 500,000 hectares of wilderness area. To the west, the Refuge borders on the Yukon River between the villages of Kaltag and Anvik.

Among the purposes of the Refuge, as prescribed in ANILCA, are to conserve of fish and wildlife populations and habitats in their natural diversity; to fulfill international treaty obligations with respect to fish and wildlife and their habitats; to provide the opportunity for continued subsistence uses by local residents; and to ensure water quality and necessary quantity, to the maximum extent practicable, within the Refuge (U.S. Fish and Wildlife Service 1987). To meet these goals, ANILCA mandates identification and description of problems which may adversely affect fishery resources and wildlife populations. This study is a portion of the effort to fulfill that obligation by examining water quality and determining concentrations of metals in aquatic ecosystems, and potential on-refuge effects from placer and lode mining occurring upstream of the Refuge.

The Innoko Refuge is a flat plain, reaching 445 meters above sea level at its highest point. Water dominates the landscape of the Refuge although the area is subject to wildfires in dry years. Extensive wetlands with innumerable lakes, streams and bogs occur over much of the Refuge, and many of the wetland areas depend on periodic flooding. White spruce (*Picea glauca*) occurs in large stands along rivers in well-drained soils. Black spruce (*Picea mariana*) muskegs develop on poorly drained, permafrost soils. The most conspicuous characteristic of vegetation within the Refuge is the complex interspersion of wetland habitat types. A primary focus of the Refuge is protection of the extensive wetlands which serve as nesting and breeding habitat for at least 240,000 breeding pairs of waterfowl (U.S. Fish and Wildlife Service 1987).

The Innoko River is the dominant water body on the Refuge and is a major tributary of the Yukon River. The Innoko River supports populations of sheefish (*Stenodus leucichthys*), northern pike (*Esox lucius*), Arctic grayling (*Thymallus arcticus*), Dolly Varden *(Salvelinus malma*), several species of whitefish (*Coregonus* spp.), chum salmon (*Oncorhynchus keta*), coho salmon (*O. kisutch*), and chinook salmon (*O. tshawytscha*) (Alt 1983, Millard 1995). Principal tributaries of the Innoko River within the Refuge are the Dishna, North Fork Innoko, Mud, Magitchlie, and Iditarod rivers.

Illinois Creek is a tributary of the Little Mud River which flows through Innoko Refuge and, via the Big Mud River, empties into the Innoko River. Prior to this study and studies by Winters (1996, 1997, 1998a, 1998b) and Morsell (1991), knowledge of fisheries in this drainage was limited. Illinois Creek provides high quality rearing habitat for coho salmon and serves as spawning habitat for summer chum salmon and coho salmon in its upper reaches (Morsell 1991; Winters 1996). Illinois Creek also supports resident populations of Arctic grayling, burbot (*Lota lota*), slimy sculpin (*Cottus cognatus*), and Alaska blackfish (*Dallia pectoralis*). Little is known about California Creek (the next tributary of the Little Mud River upstream of Illinois Creek) and the Little Mud River, except that they support populations of anadromous fish, including chum, chinook and coho salmon, and resident fish including Dolly Varden.

Little information exists regarding the soils of the Innoko River valley. General soils maps of the area indicate that all but one small area in the Dishna River drainage are histic pergelic cryaquepts. These are described as poorly drained soils with a shallow permafrost table developed in deep silty loess and alluvium. Soils tend to be hummocky with a thick (25-65 cm) accumulation of peaty material (Reiger et al. 1979).

Mineral resources of the refuge remain largely unknown (U.S. Fish and Wildlife Service 1987). The Innoko Refuge is bordered on the north by the Kaiyuh Mountains, which are part of a geologic province characterized by deposits of antimony, copper, gold, lead, tin, tungsten, and zinc, with secondary deposits of antimony, copper, and silver (Holzheimer 1926; Clark et al. 1974; Nokleberg et al. 1987). Chromite deposits also are located in the Kaiyuh Hills and at Mt. Hurst, south of the Tolstoi River (Foley et al. 1984; U.S. Fish and Wildlife Service 1987).

Occurrences of antimony (Cruz and Cobb 1986), copper (Cobb 1984a), chromite (Cobb 1975a), mercury (Cruz and Cobb 1984a), molybdenum (Cobb 1984b), platinum (Cobb 1975b), gold (Cobb 1984c), tin (Cruz and Cobb 1984b), tungsten (Cobb 1975c), and zinc (Cobb 1975d) mineralization have been documented in or near Innoko Refuge. Gold, in lode sources and placer deposits, has been the dominant mineral mined in areas surrounding the Refuge. Sites of known or indicated mineralized terrains favorable for mining and produced placer deposits are in the vicinity of Innoko Refuge (Figure 1). Many of these areas are on State of Alaska lands, Alaska Native allotments, or federally owned lands which are available for mining. Some lands east and south of the refuge have been identified as having high to very high mineral potential (Alaska Department of Natural Resources 1986). These areas contain concentrations of mining claims and activities near the Innoko/Tolstoi, Innoko/Ophir, and Innoko/Moore mining districts along the Innoko, Dishna, and Iditarod rivers (Table 1).

Preliminary grab samples collected during 1985 and 1986 from the Innoko River and its tributaries indicated that turbidity, copper, zinc, and mercury were possibly elevated (Jackson 1990). Based on these findings, a monitoring effort was conducted at 14 sites during 1987 and 1988 to determine baseline concentrations of metals in water, sediment, and fish muscle

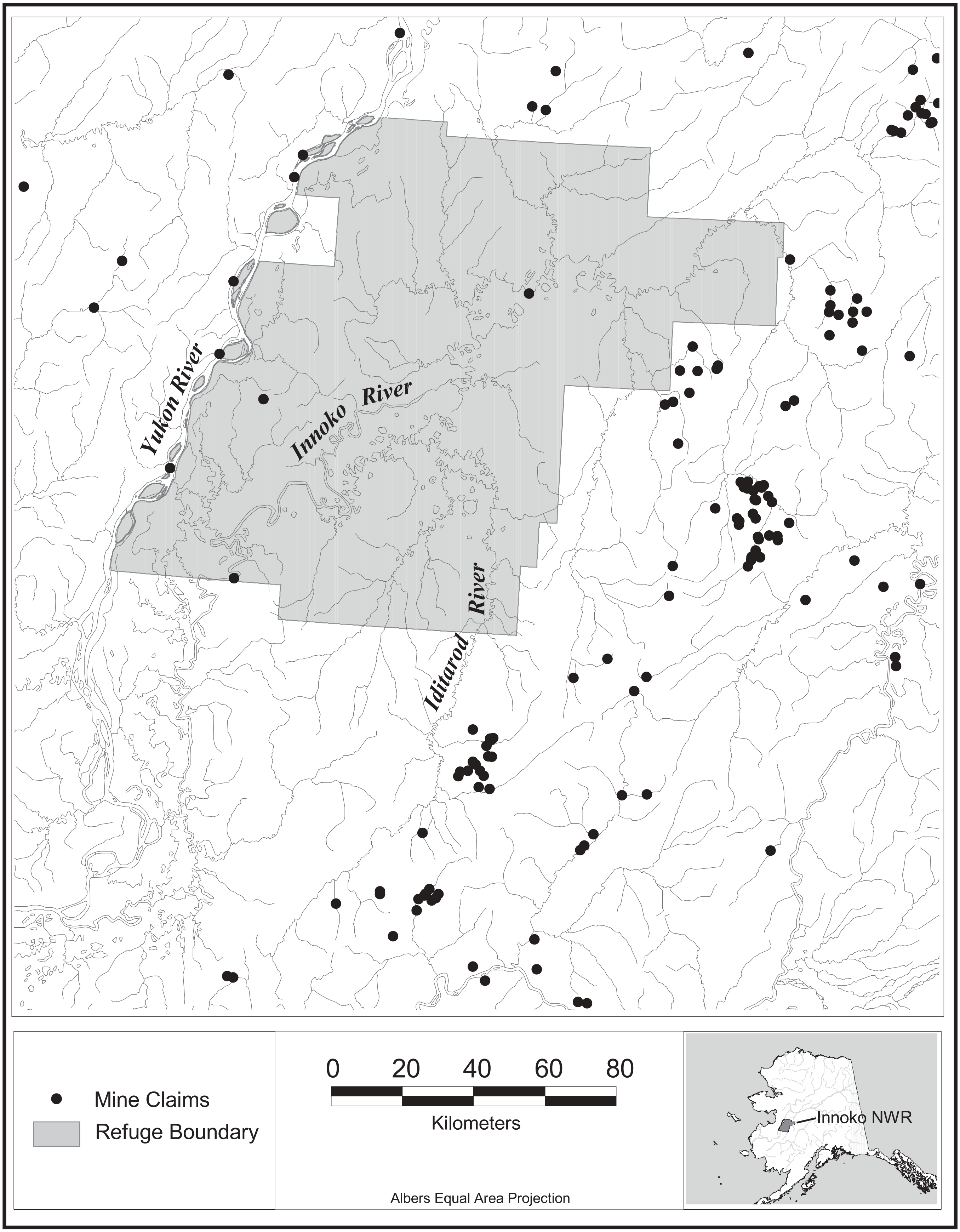

Figure 1. Active and inactive mines within the Innoko River drainage, Alaska, 1995.

Table 1. Placer gold and silver production in Innoko and Iditarod districts, Alaska, 1908-1986 (Table from Bundtzen et al. 1987).

Mining District and Stream Drainage	Known Years of Production	Gold (troy oz.)	Silver (troy oz.)	Remarks
Innoko/Tolstoi				
Graham	1917?-1963	65	6	
Colorado	1917-1966; 1978-1986	51,600	4,644	Minimum estimate used for 1978-86 production.
Bear	1917-1961; 1970-1986	10,412	1,150	No production 1961-86 included.
Cripple	1917-1955; 1978-1986	38,542	401	No production circa 1986 included.
Esperanto	1917?-1962	4,429	699	Production through 1962.
Madison	1919?-1947; 1982-1985	3,103	338	Production known through 1984.
Boob	1916-1918; 1982-1986	3,170	320	Conservative estimates.
Subtotal		111,321	7,558	
Innoko/Ophir				
Gold Run	1910-1948	1,277	245	
Beaver	1910-1950	1,640	163	
Anvil	1910-1950; 1970s-1986	3,394	12	No production circa 1986 included.
Democrat	1910-1924	947	21	
Dodge	1917?-1962	408	40	
Ester	1910-1964; 1980-1986	1,110	210	Production circa 1986 unknown.
Ganes	1907-1986	103,000	15,420	Conservative estimate.
Spruce	1909-1950;1955-1986	35,400	4,600	Conservative estimate.
Little	1908-1986	47,600	8,092	Minimum estimate for recent production
Ophir	1908-1961; 1978-1985	66,489	7,004	Production since 1961 unknown.
Victor Gulch	1909-1958	2,690	332	
Yankee	1909-1968; 1981-1986	62,500	12,650	Conservative estimate.
Spaulding	1909-1941	7,925	1,541	
Undistributed production		6,986	1,089	Locations poorly understood.

Table 1, cont.

Mining District and Stream Drainage	Known Years of Production	Gold (troy oz.)	Silver (troy oz.)	Remarks
Innoko/Moore				
Moore	1910-1966; 1980-1986	54,250	12,600	Probably conservative.
Fourth of July	1910-1920; 1982-1983; 1986	45	5	Only production circa 1986 known.
Subtotal		54,295	12,605	
Iditarod/Flat				
Boulder Creek	1917	18	4	
Black	1910-1981	5,800	700	Most production included in Otter Creek.
Malemute Pup	1912-1952	1,907	241	
Granite	1910-1956; 1980-1985	4,750	636	
Otter	1908-1986	235,721	30,628	Most production prior to 1968, included Black Creek.
Slate	1915-1951	3,483	592	Last mining recorded 1951.
Flat	1910-1966; 1975-1985	477,039	51,875	Includes Mohawk, Upgrade, and other headwater steams.
Prince	1913-1986	33,194	3,979	Accurate mine records provided by operator in 1986.
Happy	1910-1984	127,486	17,210	May have included production from Chicken and Willow creeks.
Willow Bench	1915?-1967; 1984-1986	41,948	5,033	Probably conservative; incomplete records.
Chicken	1912-1986	24,800	3,174	Probably conservative. Production records from 1940-86 are absent.
Glen Gulch	1912-1958	10,421	1,231	Last record of production 1958.
Idaho Bench	1910-1965; 1984-1986	330	15	Only circa 1986 production.
Undistributed Iditarod Production	1910-1914	482,382	72,278	Estimates from entire Iditarod/Flat district prior to systematic record keeping.
Undistributed prod.		1,645	42	
Subtotal		1,450,924	187,638	
Total		1,957,876	246,741	

A note from Bundtzen et al. (1997) states that this compilation is based on systematic examination of all available published reference material, unpublished U.S. Mint return data, and interviews with recent/contemporary (circa 1986) mine operators. The data for U.S. Mint returns generally span the period 1914-1972 and hence do not show complete production records for the 1907-1912 discovery era of the Innoko/Ophir and Iditarod/Moore districts. No mint data are available after 1972, when gold was decontrolled by federal legislation. Some 20 to 27 mine operators have produced gold, more-or-less continuously, since the late 1970s to 1986. Bundtzen et al. added production to U.S. Mint and published data for these streams only when accurate estimates were provided by mining companies. Hence, all stream and district totals for bullion production must be regarded as conservative. Undistributed production are U.S. Mint return information from the Innoko and Iditarod districts that cannot be assigned to known mine areas.

from selected drainages on the refuge. Jackson (1990) reported relatively high concentrations of chromium (water, sediment, tissue), nickel (sediment), zinc (water), and possibly aluminum (water). Sediment and water data from mined streams showed no significant differences when compared to controls; however, sample sizes were too small for adequate comparisons. Mercury concentrations in fish muscle were elevated at both the mined and control sites. Immediate remedial action was not indicated and additional monitoring was recommended at two to three year intervals, particularly if new development projects and mining activities occurred.

Threats to Innoko National Wildlife Refuge

Beginning in the late 1880's, prospectors worked the Innoko River in search of gold. Placer mining has occurred in the headwaters of the Innoko River drainage since the discovery of gold on Ganes Creek in September 1906. The Iditarod Mining District developed following the discovery of gold in that drainage in 1908. By 1912, more discoveries followed on Ophir Creek and numerous small streams. Since that time, gold rushes have occurred on the upper Innoko River, the Ophir Mining District, and the Iditarod Mining District, all upstream of Innoko Refuge. Gold mining ceased during World War I and World War II but resumed following these conflicts. A rise in gold prices in the early 1970's caused a dramatic increase in mining activity. Placer mining continues to occur upstream of Innoko Refuge. The DeCourcy Mountain Mine, located on a tributary of the Iditarod River, has produced over 1,200 flasks (35 kg/flask) of mercury but it is not presently mined (U.S. Fish and Wildlife Service 1987). During 1994, placer gold mining was conducted on Colorado Creek and Madison Creek, tributaries of the Innoko River (Swainbank et al. 1995). No valid mining claims are known to exist on the Refuge and Refuge land is not open to new mining activities. However, private inholdings within the Refuge are subject to mining.

During placer mining large amounts of overburden are frequently removed to extract gold from ancient alluvia. Mined sediment-rich effluent, transported in suspension and as bedload, can cause elevated turbidities in the water and blanket the stream bottom, making it unsuitable for benthic aquatic life (Bjerklie and LaPerriere 1985; LaPerriere et al. 1985; Wagener and LaPerriere 1985; Weber and Post 1985; Van Nieuwenhuyse and LaPerriere 1986; Lloyd 1987; Lloyd et al. 1987; Weber Scannell 1993). Weber and Post (1985) found a 75% reduction in benthic invertebrate densities up to 92 km (57 miles) below mining activity in a heavily mined area. Sediments from mining activities could be seen as far as 160 km (100 miles) downstream from the source in some drainages. In addition, mining activities may mobilize trace metals such as arsenic, cadmium, copper, lead, mercury, and zinc, thus making them more available for biologic uptake (LaPerriere et al. 1985). These metals can be toxic to aquatic organisms in receiving streams. Concentrations of arsenic and mercury in streams with active placer mines in Alaska have been shown to be close to the estimated maximum no-effect concentrations for juvenile Arctic grayling (Buhl and Hamilton 1991). Since 1985, Environmental Protection Agency (EPA) requirements for 100 percent recycling of process water during medium- and large-scale placer mining have significantly lessened, but not eliminated, these problems in Alaska (Alaska Department of Environmental Conservation 1991).

In 1985, a mining company proposed building a heap-leach gold mine using a cyanide gold-extraction process near Illinois Creek (U.S.M.X. 1995). Production began at the Illinois Creek Mine in 1997 (Swainbank and Clautice 1998), the first large-scale heap-leach gold mine in Alaska. The mine and accompanying facilities are now located on hillsides above both sides of Illinois Creek, with a road around the headwaters connecting the two areas. Releases of water containing cyanide and/or metals could impact U.S. Fish and Wildlife Service (FWS) trust resources in Illinois Creek, the Little Mud River, and Innoko Refuge. The mining company has detected arsenic, cadmium, copper, lead, and mercury in waste rock and ore analyses (SRK 1995). The rock composing the hill on which the mine lies is extremely permeable. Therefore, any discharges to groundwater also may enter Illinois Creek or the Little Mud River in a relatively short period of time due to the abundance of springs, both warm and cold, feeding these streams. Total recoverable copper was detected in low concentrations (0.005 mg/L) in the Little Mud River by a U.S.M.X. contractor (memorandum from Jokela to Richins 1994). Increases in copper concentrations could cause avoidance of the stream by fish (Giattina et al. 1982), and may alter food consumption and reduce growth of fish (Sandheinrich and Athison 1989). Copper was identified as the major toxic component and accounted for 97% of the summed toxic units of an environmentally relevant mixture of arsenic, copper, lead, and zinc simulating placer mining effluent in early life stages of Arctic grayling and coho salmon (Buhl and Hamilton 1991). The LC50 for dissolved copper in Arctic grayling (0.2 g to 0.34 g) from Alaska was 0.003 mg/L (Buhl and Hamilton 1991). For 0.47 g and 0.87 g Alaskan coho salmon, the LC50's for dissolved copper were 23.9 and 31.9 µg/L, respectively (Buhl and Hamilton 1991). Discharges from similar mining operations in other states have contained cyanide and metals in toxic concentrations. Cadmium concentrations between 1 and 3 µg/L have caused reduced growth, survival, and fecundity of brook trout (*Salvelinus fontinalis*) (Eisler 1985).

A reconnaissance study for constructing a road on the east and north sides of the Refuge between McGrath and Ruby is currently underway. One route, if adopted, would result in a road along the Innoko River from Cripple Landing to Ophir, a reach of river upstream from the refuge boundary. A new road, regardless of its route, will increase access and potential mining activity upstream of the Innoko Refuge.

Collateral and Concurrent Studies

This study was part of a suite of studies documenting baseline conditions and assessing threats to Innoko NWR, including genetic differentiation in salmon runs, examination of histological changes in juvenile salmon to assess exposure to mine effluents, and documentation of benthic macroinvertebrate fauna.

When determining management and regulatory actions, factors to consider include assessing the abundance and value of the natural resources at risk. Determinants of a resource s value include its rarity and restoration potential, should the resource become damaged. Small, discrete, unique salmon populations are inherently more valuable and vulnerable than small salmon runs that are inseparable from large populations. In a case where two populations receive equal damage, the population with the smaller size and geographic range would likely suffer the greater loss of genetic diversity and require a longer period of time to be restored. Effects from mining could affect fish habitat which could reduce fish production and change the genetic diversity of affected small populations. Determination of the population structure of chum salmon and coho salmon from Illinois and California creeks with comparisons to salmon from other drainages, including Tolstoi Creek within the Innoko River drainage, was reported by Spearman et al (2002).

Tissue examination is a sensitive method of evaluating exposure of fish to contaminants. Lanno and Dixon (1994) found that histological change of thyroidal tissue was the most sensitive variable measured among growth, physiological, and reproductive variables for fish exposed to thiocyanate. West and Deschu (1984) found that histopathologic changes to Arctic grayling are more likely to occur in fish from placer-mined streams than from streams without mining. Changes were attributed to the physical effects of high sediment and metal concentrations in water. Determination of baseline histologic conditions of coho salmon from Illinois Creek was conducted by the Alaska Department of Fish and Game in conjunction with this study. Documenting histologic change in juvenile coho salmon could be the most sensitive measure of cyanide discharges to Illinois Creek. Histological study results are presented in Winters (1996) and are included in Appendix N of this report. Enumeration of adult and juvenile salmon at Illinois Creek was also conducted (Winters 1996, 1997, 1998a, 1998b).

Benthic macroinvertebrate fauna are also susceptible to injury from metals and cyanide, particularly from cadmium and copper (Timmermans 1993). Clements et al. (1988) and Gower et al. (1994) have shown differences in proportions of major taxa and reduced overall abundance of the macroinvertebrate community in streams contaminated with heavy metals. Benthic samples were collected at Illinois Creek for analysis of the macroinvertebrate fauna according to EPA Rapid Bioassessment Protocols. This information was intended to evaluate the effectiveness of biomonitoring and bioassessment relative to mining disturbances. However, post-mining sampling was not possible within the time span of the study, so these data serve as baseline information. The study was conducted by the Environment and Natural Resources Institute, University of Alaska, Anchorage, through a grant from EPA. The results are presented in Major (1997).

In 1997, the Water Resources Branch of the FWS began a five-year water resources inventory and assessment at Innoko Refuge. The study, which includes water quality data, is primarily an investigation of stream discharge. A progress report covering the first two years of the study was completed by Linne (2000).

Objectives

The objectives of this study were to:

1. Determine selected metal and metalloid concentrations in water, sediment, and fish tissue at sites within and upstream of the Innoko Refuge.

2. Estimate the number of coho and chinook salmon spawning in Illinois and California creeks.

3. Determine the uniqueness of chum and coho salmon populations from Illinois and California creeks by comparing their genetic characteristics with those from other locations.

4. Determine the histologic baseline conditions of juvenile silver salmon in Illinois Creek.

Objectives 1 and 3 are addressed in this report. Objective 2 was addressed by Winters (1996, 1997, 1998a, 1998b) and objective 4 was addressed by Winters (1996) (Appendix N).

METHODS AND MATERIALS

Sample Sites

Samples were collected from 20 sites on the Innoko Refuge and 6 sites northeast of the Refuge (Table 2, Figure 2).

Table 2. Descriptions of sample sites on and adjacent to Innoko National Wildlife Refuge, 1995-1997 (latitude and longitude are in decimal degrees).

Site	Drainage	Latitude	Longitude
On-Refuge Sites			
9	Tolstoi River	63.21059 N	157.05036 W
10	Madison Creek	1996, 63.24495 N 1997, 63.24538 N	157.05808 W 157.09052 W
12	Innoko River, upstream of the confluence with North Fork Innoko River	1996, 63.48366 N 1997, 63.48866 N	156.36860 W 156.37125 W
15	North Fork Innoko River	1996, 63.49396 N 1997, 63.4760 N	156.36126 W 156.3760 W
16	Finland Creek	1996, 63.32081 N 1997, 63.32878 N	156.51276 W 156.52973 W
17	Scandinavian Creek	1996, 63.36385 N 1997, near 1996 site	156.37454 W
18	Wapoo Creek	1996, 63.4604 N 1997, 63.4744 N	157.0991 W 157.10506 W
19	Lower Finland Creek	63.36300 N	157.01176 W
26	Little Mud River, at refuge boundary	1996, 63.56895 N 1997, 63.57297 N	158.05720 W 158.05124 W
27	Dishna River	63.18452 N	157.19396 W
28	Big Mud River	1996, 63.56265 N 1997, near 1996 site	157.13870 W
29	Iditarod River	62.41774 N	158.02312 W

Table 2 Cont.

Site	Drainage	Latitude	Longitude
30	Big Yetna River	62.4491 N	158.3722 W
31	Little Yetna River	62.51532 N	158.30074 W
32	Galatea Creek	1996, 63.50295 N 1997, 63.50244 N	157.17356 W 157.17717 W
33	Moose Creek	1996, near 1997 site 62.42032 N	 157.54407 W
34	First Chance Creek	62.49032 N	157.56314 W
35	Magitchlie Creek	1996, 63.55792 N 1997, 63.56361 N	158.22016 W 158.22715 W
36	Innoko River downstream of Iditarod River, Northern Pike Hole	63.0112 N	158.5718 W
37	Middle Magitchlie Creek	1997, 63.53765 N	158.20787 W
Off-Refuge Sites			
20	Upper California Creek	64.07924 N	157.42134 W
21	California Creek, near its confluence with the Little Mud River	64.02027 N	157.48000 W
22	Little Mud River, downstream of Illinois Creek	64.00468 N	157.53806 W
23	Little Mud River, upstream of Illinois Creek	64.00454 N	157.51406 W
24	Illinois Creek, 100m upstream of bridge	64.0235 N	157.5200 W
25	Illinois Creek, near confluence with Little Mud River	64.01690 N	157.52076 W

Samples and measurements were collected for water quality variables at off-refuge sites in 1995 and 1996 and at on-refuge sites in 1996 and 1997 (except for Site 37 which was sampled only during 1997). Samples for total and dissolved metals analysis were collected at off-Refuge sites in 1996 and at on-Refuge sites in 1996 and 1997. Triplicate sets of water samples were collected for analysis of water quality variables and total and dissolved metals. Triplicate sets of sediment

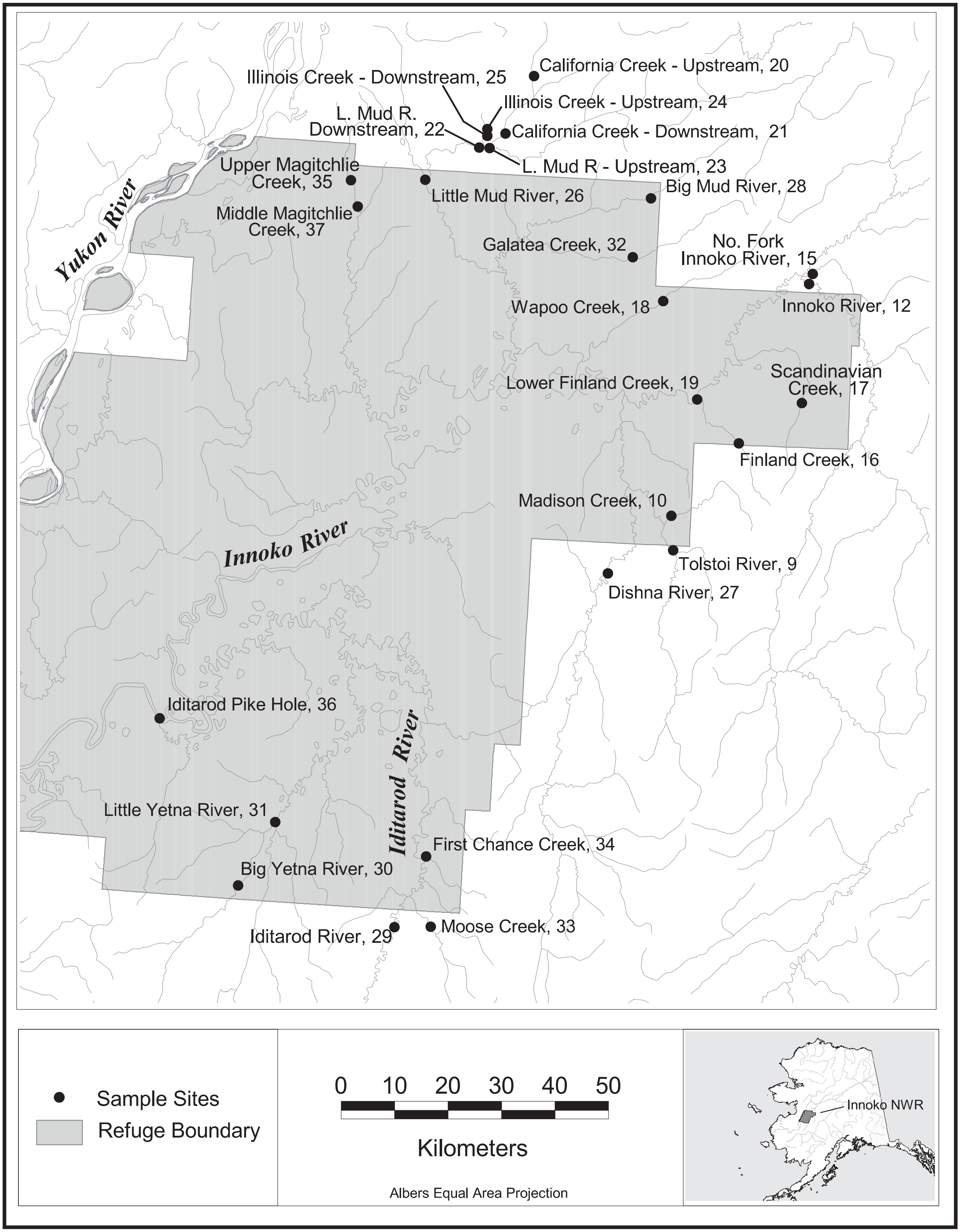

Figure 2. Sample sites within the Innoko River drainage, Innoko National Wildlife Refuge, Alaska, 1995-1997

samples were collected for metals analysis. Fish tissue was collected at several sites for metals analysis.

Collection Methods

Water Quality Samples

Triplicate 1-L water quality samples were collected in plastic bottles. Water quality sample containers were triple-rinsed in the water to be sampled prior to sampling. Water samples were surface grabs and each sample bottle was extended into the current upstream from the collector to avoid contamination due to resuspension of sediment or from the collector. Sample bottles were filled to the top to minimize gaseous exchange. Each sample bottle was labeled prior to collection and placed in a cooler for transport to a field laboratory for analysis.

Samples were analyzed for pH, total alkalinity, total hardness, conductivity, turbidity, total suspended solids (1996 only), settleable solids, and dissolved oxygen (1996 only); additional variables measured in 1997 included ammonia, nitrate, and phosphate. Hardness and alkalinity were determined using a Hach digital titrator and Hach (1992) methods. Measurements of pH were made using an Orion Model SA250 (1996) or an Orion model 290A (1997) pH meter equipped with an Orion Sure-Flow Ross combination electrode and automatic temperature compensation. In 1996, prior to each measurement series, two-buffer calibrations were performed using pH buffers accurate to ± 0.02 pH units which bracketed the pH of the samples. In 1997, the pH meter was calibrated prior to going into the field and checked at the end of the analyses. In 1996, water temperature, conductivity, and dissolved oxygen were measured in the field using a Cole-Parmer Model 5566-22 Water Analyzer. In 1997, water temperature was measured in the field using a Cole-Parmer Temptestr digital thermometer and conductivity was measured using a Hach Model CO150 conductivity meter in the field laboratory. Conductivity standards were used to check meter performance prior to the measurement series in the field during 1996, and prior to going into the field and at the end of analysis in the field laboratory during 1997.

Three measures of solids in water were made. Turbidity was measured using a Hach Model 2100P Portable Turbidity Meter calibrated with Gelex secondary standards for 1, 10, and 100 nephelometric turbidity units (NTU) which were calibrated immediately prior to the sampling trip and checked in the field laboratory. A single total settleable solids measurement for each sample site was conducted using the Imhoff Cone Method for 1-L samples (Greenberg et al. 1992). If settleable solids occurred, but did not exceed 0.1 mL/L, "trace" was recorded. Total suspended solids were determined by Northern Testing Laboratory, Fairbanks, Alaska. Ammonia, nitrate, and phosphate in water were determined using Salicylate, Cadmium Reduction, and Ascorbic Acid methods (Hach 1992), respectively, with a Hach DR2010 spectrophotometer with a pour-through cell in the field laboratory.

Trace Elements in Water

Water samples for metals analysis were surface grab samples collected in the same manner as the water quality samples. Three water samples for total metals in water and one to three (1996) or three (1997) samples for dissolved metals in water were collected from each site. Dissolved metals samples were filtered in the field using 0.45-µm Gelman polyethersulfone syringe filters with Luerlock fittings. Samples for total metals and dissolved metals analysis were acidified to a pH <2 with 2.0 mL HNO_3 (Ultrix)/L sample. All trace metal water samples were collected in previously unused 500-mL acid-precleaned high-density I-Chem polyethylene bottles. During 1996, triplicate water samples were collected in 250-mL teflon bottles supplied and cleaned by Frontier Geosciences Inc. for total mercury analysis. Samples for total mercury analysis were acidified with laboratory grade HNO_3.

Trace Elements in Sediments

Three composite sediment samples were collected from shallow water at each site. Samples were collected using acid-washed plastic scoops, and transferred to new acid-cleaned 500-mL I-Chem polyethylene jars. Fine-grained silt was sought for sampling in all cases. During 1996, upon returning to the field camp, each sample was homogenized using an acid-washed glass rod. In 1997, sufficient stream water was added to each sample to allow homogenization by shaking. Each sample bottle was shaken in the field, refrigerated upon returning to field camp, and allowed to settle for 24-hours, after which the supernatant was decanted and the sediment placed in a freezer. Each sample bottle was labeled immediately prior to collection and placed in a cooler for transport to the field camp.

Trace Elements in Fish Tissues

Fish were collected by angling. Target fish species included Arctic grayling and northern pike, with a collection goal of five fish per site. Fish were weighed to the nearest gram, using an Ohaus Model LS5000 electronic balance, and total and fork lengths were measured to the nearest millimeter, using a tape measure. Liver, kidney, and muscle samples from each fish other than salmon fry and slimy sculpin (which were frozen whole) were dissected using acid-cleaned stainless steel instruments. A new stainless steel scalpel blade was used for each specimen. Samples were transferred to pre-cleaned 250-mL or 125-mL I-Chem bottles. Each sample was labeled immediately prior to collection and placed in a cooler for transport to a freezer. Scale samples were collected from each fish and clithra were collected from each northern pike for aging.

Genetic Patterns in Chum Salmon and Coho Salmon

Two collections were made for each species within the Innoko River drainage and from tributaries to the Tanana River (Table 3). Collections from Tanana River sites were used as outgroups for comparisons of genetic differentiation on varying geographic scales. Chum salmon were collected using weirs, gillnets, and angling. Coho salmon were collected using gill nets, angling, and minnow traps (for juveniles). All samples were collected during 1997 except coho salmon samples from California Creek which were collected during 1996.

Pectoral fin clips were collected from chum salmon and stored in 100% ethanol until processing. Pectoral fin clips (~1 cm^2) from adult and dorsal fin clips from juvenile coho salmon were collected and stored in either 70-100% ethanol or dried in paper envelopes until their arrival at the laboratory, at which time samples were stored in 100% ethanol.

Laboratory Analyses

Tissue samples from 1996 and 1997 and water samples from 1997 were analyzed by Environmental Trace Substances Research Center, Rolla, MO. A brief description of their analytical methods follows.

Each tissue sample was weighed and then frozen. Frozen samples were freeze-dried in a Labcono Freeze Dryer 8 and homogenized using a blender or Spex Industries, Inc. Model 8000 mixer/mill with tungsten-carbide vial and balls. The percent moisture in tissue samples was determined by placing a weighted aliquot of sample in a Fisher Isotemp oven and drying at 103 - 105°C. The dried sample was then weighed and the percent moisture was calculated. Samples too small for oven-dried moisture determination had the percent moisture calculated from moisture lost during freeze-drying.

Digestion for ICP analysis of muscle samples, water samples for arsenic only, and all tissue samples for arsenic and selenium by Hydride Generation Atomic Absorption Spectrophotometery (HGAA) analysis was as follows: fifteen milliliters of HNO_3 and 2.5 mL of $HClO_4$ were added to approximately 0.5 g of sample for tissue or 50 mL of water sample. After the initial reaction subsided, heat was increased and the samples refluxed overnight. After refluxing, the HNO_3 was driven off and 2 mL of concentrated $HClO_4$ was added. Finally, the samples were heated, cooled and diluted using deionized water to a total of 50 mL of solution, and analyzed.

Water and kidney were digested for mercury analysis using 0.5 g of sample and 5 mL of HNO_3. This mixture was refluxed for 2 hours and the samples were diluted with 1% v:v HCl and analyzed. Water samples for analysis of cadmium, chromium, nickel, and selenium were analyzed without prior digestion.

For samples of limited size to be analyzed using ICP or cold vapor for mercury, 0.5 g of sample, when available, was placed into a teflon bomb with 5 mL of concentrated HNO_3 and 3 mL of H_2O_2. The samples were allowed to set for 12 hours and microwaved in the teflon bombs. Digested samples were diluted to 50 mL with deionized water and analyzed. Concentrated HCl also was added to samples for mercury analysis.

Table 3. Summary of samples collected for determination of genetic differences in chum salmon and coho salmon, Innoko and Tanana river drainages, 1996-1997. From Spearman et al. 2002.

Location	Year	Maturity	n
	Chum Salmon		
Innoko River			
California Creek	1997	adult	100
Tolstoi Creek	1997	adult	115
Tanana River			
Chena River	1997	adult	50
Salcha River	1997	adult	50
	Coho Salmon		
Innoko River			
Illinois Creek	1997	juvenile	179
California Creek	1996	juvenile	116
Tanana River			
Clearwater Creek	1997	adult	56
Nenana River	1997	adult	56

ICP analysis of water and muscle samples was accomplished using a Jarrell-Ash Model 1100 Mark III with 40 analytical channels, controlled by a Digital Equipment Company 11/23+ computer with two RLO2 disk drives, and DEC VT100 terminal. The instrument was standardized with a series of seven standards containing 3 elements. ICP analysis of water samples for analysis of cadmium, chromium, nickel and selenium, and kidney samples was accomplished using a Perkin-Elmer Model ELAN 5000. The instrument was standardized with two multi-element standards.

Arsenic in water and tissue, and selenium in tissue were analyzed by HGAA using a Varian VGA-76 (selenium) or a Perkin-Elmer NHS-1 (arsenic) hydride generation accessory on either a Perkin-Elmer Model 603 AA or Model 3030 (B) AA. Electrodeless discharge lamps were used. Standards were prepared by dilution of Fisher 1000 mg/L stock in 10% v/v HCl in the range of 0 to 20 µg/L.

All sample digests for mercury were analyzed using a Perkin-Elmer Model 403 AA. The samples were mixed with hydroxylamine for preliminary reduction, then stannous chloride for reduction to mercury vapor. The vapor was separated from the liquid and passed through the cell mounted in the light path of the burner compartment. Peaks were recorded and the heights were measured. Standardization was done with at least five standards in the range of 0 to 10 µg/L.

Detection limits were determined by taking ten integrations of the zero standard; three times (ICP) or two times (HGAA) the standard deviation of the mean was used as the detection limit. For ICP, the final detection limit for each element was further increased by 4% of the magnitude of the spectral interferences from the other elements.

Sediment samples for 1997 were analyzed by Trace Element Research Laboratory, Texas A&M Research Foundation, College Station, Texas. For ICP and GFAA analysis, wet sediment was homogenized in the sample container, freeze dried, and homogenized to a fine powder. Approximately 0.5 g of powdered sediment was digested in 10 mL of aqua regia (1:4 v:v HNO_3:HCl) for 2 hours. Samples were diluted to 30 mL with distilled/deionized water, centrifuged, and analyzed. Samples for mercury analysis were digested using a modified EPA Method 245.5 and 245.6. Following homogenation and freeze drying with a Tekmar Tissumizer, subsamples were digested using HNO_3, H_2SO_4, $KMnO_4$, and $K_2S_2O_8$ in a water bath at 90-95°C. $(NH_3OH)Cl$ was added and the samples were analyzed by cold vapor AA. Moisture content of the samples was determined by measuring the weight loss during freeze-drying. Grain sizes of the samples were determined using a combination of the wet sieving and pipette methods.

Mercury in water samples for 1996 was determined by Frontier Geosciences, Seattle, Washington, using BrCl oxidation, $SnCl_2$ reduction, purging onto gold, and cold vapor AFS detection (EPA Method 1631).

Water and sediment samples for 1996 were analyzed by Research Triangle Institute, Research Triangle Park, North Carolina. Sediment samples were digested using microwave digestion in a teflon vessel using 0.5 g of freeze-dried sample. Following addition of 5 mL of Baker Instranalyzed nitric acid, they were heated for 3 minutes at 120 watts, 3 minutes at 300 watts, and 15 minutes at 600 watts. The samples were cooled, diluted to 50 mL with water, and analyzed. Digestion for total metals in water was similar except they were not freeze-dried.

Samples collected for genetic analysis were processed and analyzed by the U.S. Fish and Wildlife Service Fishery Genetics Laboratory, Anchorage, Alaska. Nucleic acids were extracted from approximately 25 mg of tissue for chum salmon and from 2 mg (juvenile) to 25 mg (adult) of coho salmon fin tissue. For a complete description of DNA extraction and assay methods see Spearman et al. 2002. The mtDNA segment, NADH dehydrogenase-5/6 (ND5/6) for chum salmon and mtDNA segments cytochromeB and ND5/6 for coho salmon, were amplified using the polymerase chain reaction (PCR). For chum salmon, restriction enzymes *BstNI* and *AseI* were used to cleave the amplified ND5/6 segment. Each fish was assigned a composite mtDNA haplotype based on individual haplotypes observed from the restriction digests (Spearman et al.

2002). For coho salmon, restriction enzymes *BfaI*, *BsaJI*, and *BstNI* were used to cleave the amplified cytB segment and restriction enzyme *DdeI* was used to cleave the amplified ND5/6 segment. Restriction fragment patterns were identified visually and each fish was assigned a composite mtDNA haplotype based on individual haplotypes observed from each of the four restriction digests. Three microsatellite loci were labeled with fluorophore HEX (Perkin Elmer), and amplified using PCR (Spearman et al. 2002).

Six microsatellite loci were screened for variation using PCR conditions optimized for each locus. Samples were screened for variation using [^{32}P]ATP end-labeled primers following the procedures of Scribner et al. (1998), except that the T4 polynucleotide kinase was obtained from Epicentre Technologies (Spearman et al. 2002).

Allele frequency summaries and heterozygosity values were generated using GENEPOP 3.1d. Calculations were performed using GENEPOP 3.1d for coho salmon and ARLEQUIN 1.1 for chum data. Tests of linkage disequilibrium were performed with ARLEQUIN 1.1. Tests for departure from Hardy-Weinberg equilibrium were performed for each collection and microsatellite locus. Genotypic variability among collection was partitioned with F_{st} (Wright 1965). The microsatellite F_{st} was calculated using ARLEQUIN 1.1 for chum salmon and GENEPOP3.1 for coho salmon. For mtDNA data, AMOVA1.55 was used for both species. Tests of heterogeneity were used for each locus to test the hypothesis that allelic frequencies were different among collections. GENEPOP3.1 was used for microsatellite loci, and the Monte option (Roff and Benzen 1989) in REAP (McElroy et al. 1991) was used for mtDNA. The sequential Bonferroni technique (Rice 1989) was used to adjust each test of heterogeneity.

Pairwise genetic distances were calculated for both species and assessed with neighbor-joining cluster analysis using PHYLIP 3.57 (Felsenstein 1995). The strength of clustering was evaluated by performing consensus tests with 1000 bootstraps using PHYLIP 3.57.

Quality Assurance/Quality Control

Field Collections

Sampling followed a written study plan containing sample location designations, the types of samples to be collected at each site, and the sampling order. At the time of collection, samples collected and other pertinent data were recorded in a field notebook. A sample catalog was prepared for each sample matrix prior to submittal of samples to the analytical laboratory. The catalog contained a regional identifier for the sample batch; study objectives; instructions to the laboratory on requested analyses; identification of the detection limits requested; and a tabulated summary of all samples including species, tissue type, collection location, collection date, weight, and other variables.

Water quality measurements (except some settleable solids and all suspended solids) were performed on the same day as collection. Laboratory quality control procedures were followed during analysis of water quality samples. These included instrument calibrations or calibration checks prior to measurement of pH, conductivity, and turbidity; use of fresh reagents in titrations for hardness and alkalinity; and repeat analysis if a replicate sample deviated significantly from other measurements. Analytical performance for hardness and alkalinity measurements were checked using the standard additions method (Hach 1992); analytical performance for ammonia, nitrate, and phosphate was demonstrated by analysis of standard solutions.

Sediment sampling followed water sampling. All collection methods and equipment minimized external contamination; for example, all collection equipment was acid-washed. Samples were frozen after collection and shipped to the analytical laboratory in coolers with dry ice by overnight air courier.

Fish were rinsed with river water from the site of collection to minimize external contamination. Morphometric measurements were made on site. Dissections of kidney, liver, and dorsal muscle were performed by the collector at the Refuge field camp using acid-washed stainless steel and teflon dissection equipment on a clean surface, with new stainless steel blades. Tissues were immediately placed in storage containers. Samples were shipped to the laboratory in coolers with dry ice by overnight air courier.

Laboratory Analysis

The U.S. Fish and Wildlife Service maintains contracts with several analytical laboratories. These contracts are managed by the Patuxent Analytical Control Facility, Patuxent National Wildlife Research Center (PACF), Laurel, Maryland. Contract laboratories are selected by a PACF technical committee using a process involving the correct analysis of samples submitted to prospective laboratories by PACF, and a review of the laboratory, its procedures, facilities, experience, personnel, and cost structure. Additional information on the contracting and QA/QC procedures used by PACF are contained in Appendix B.

Laboratory quality assurance/quality control (QA/QC) procedures, screening criteria to accept or reject analytical data, screening results, and the basis for rejection of certain analytical data are described in Appendices B and C. In summary, duplicate (split) samples, spiked samples, standard reference materials (SRMs), and blanks were used to evaluate data quality. QA/QC data for water, sediment (except SRM), and tissue data were considered acceptable for publication if they met the following criteria: mean relative percent difference (RPD) of duplicate analyses 20%, mean spike recovery 80 - 120%, and mean SRM within ±20% of the certified mean. Sediment QA/QC data for SRMs needed to be within ±20% of the mean recovery for all laboratories contracted by PACF, because SRMs for sediment are based on total metals analysis; PACF contract laboratories analyze metals in sediment using strong-acid digestion without HF, in an effort to approximate the bioavailable fraction of the total metals in sediment. Table 4 identifies the method limits of detections (LODs) and acceptable analytical data sets for water, sediment, and fish tissue.

Table 4. Limits of Detection for analyses of water (mg/L), sediment (mg/kg dry weight), and fish tissue (mg/kg dry weight) from Innoko National Wildlife Refuge, Alaska, 1996-1997. Analytes which are shaded failed Quality Assurance/Quality Control screening and were not used. N/A indicates that the analyte was not included in the laboratory analysis.

Matrix	Water		Sediment		Kidney	Liver	Muscle	Whole Body	All Tissue
Year	1996	1997	1996	1997	1996	1996	1996	1996	1997
Aluminum	0.0222	0.03	103	3.44	20	4	2	5	5
Arsenic	0.0056	0.0004	0.53	0.487	0.3	0.4	0.06	0.4	0.2
Boron	0.0111	0.005	5.19	6.69	3	0.5	0.7	1	1
Barium	0.0011	0.0005	3.09	0.0625	0.5	0.06	0.06	0.09	0.1
Beryllium	0.0006	0.0005	0.21	0.688	0.02	0.02	0.005	0.01	0.05
Calcium	N/A	N/A	N/A	33.4	N/A	N/A	N/A	N/A	N/A
Cadmium	0.0006	0.0001	0.21	0.0242	0.1	0.1	0.03	0.06	0.1
Chromium	0.0056	0.003	5.13	0.625	0.2	0.2	0.03	0.04	0.8
Copper	0.0056	0.007	5.23	0.312	4	0.6	0.6	0.8	0.5
Iron	0.0222	0.007	106	6.88	4	0.6	0.7	0.7	4
Lead	0.0111	0.01	5.3	0.365	0.03	0.04	0.04	0.08	0.4
Mercury[1]	0.0003	0.0003	0.1059	0.0111	0.03	0.03	0.03	0.004	0.05
Magnesium	0.0222	0.001	106	6.25	2	0.2	0.1	0.4	0.5
Manganese	0.0022	0.001	4.24	0.669	0.8	0.1	0.2	0.2	1
Molybdenum	0.0044	0.004	5.31	0.625	1	0.3	0.4	0.4	0.6
Sodium	N/A	N/A	N/A	3.13	N/A	N/A	N/A	N/A	N/A
Nickel	0.0056	0.001	5.19	0.152	0.09	0.1	0.04	0.06	0.6
Sulfur	N/A	N/A	N/A	3.13	N/A	N/A	N/A	N/A	N/A
Selenium	0.0056	0.002	0.53	0.124	0.5	0.2	0.2	0.2	0.2
Strontium	0.0022	0.0006	2.12	0.0312	0.3	0.07	0.02	0.4	0.5
Vanadium	0.0044	0.007	5.3	0.625	4	0.7	0.5	0.9	0.6
Zinc	0.0111	0.006	5.3	3.44	0.5	0.08	0.2	0.2	0.2

[1] All mercury analyses of water listed as <0.0003 were performed by Research Triangle Institute, all other mercury analyses were performed by Frontier Geosciences with an LOD of 0.22 ng/L.

The qualitative/quantitative nature of the sample data was determined based on the relationship of the data to the LOD or the maximum blank value reported by the laboratory, whichever was greater. Concentrations reported for an analyte that are less than twice the LOD or maximum blank should be considered qualitative only. Values between 2 and 10 times the LOD or maximum blank should be considered semi-quantitative, i.e., liable to more variability than in the zone of quantitation, where measured values are greater than 10 times either the LOD or the greatest blank value.

There were data quality concerns for some analytes. Mean concentrations of cadmium in sediment were greater at all sites in 1996 than in 1997 (Figure 3). The LODs for these two years were almost an order of magnitude different, 0.21 mg/kg for 1996 versus 0.0242 mg/kg for 1997, which resulted in a small percentage of data from 1997 being qualitative. Although this difference in precision may be a contributing factor, we suspect that another but unidentified systematic analytical inconsistency between years is responsible for this occurrence. Similar, but less extreme, differences occurred for lead, magnesium, manganese and nickel in sediment where 1996 data were greater, and for arsenic and iron where1997 data were greater. Accordingly, we are less suspect of laboratory inconsistencies for these analytes than for cadmium.

For 1996, arsenic and boron in water and mercury and molybdenum in sediment had high LODs when compared to sample analysis values for water and sediment samples from 1997. The high LODs resulted in high percentages of <LOD values for 1996.

The northern pike kidney sample analyses from the Dishna River for 1996 had high LODs due to a small sample volume. In general, kidney samples for 1996 had greater LODs than other tissues due to small sample volumes. Similarly, for 1997, several kidney samples had low sample volumes which resulted in high LODs for those analyses including: Tolstoi River replicates A, C and D; and samples from Finland and Scandinavian creeks and the Iditarod River (Appendix L). Lead and nickel in tissue for 1997 had high LODs (0.4 mg/kg and 0.6 mg/kg, respectively), resulting in many non-detects. However, lead for 1996 had an LOD of 0.04 mg/kg and also had many non-detects. Sample J from Upper California Creek, a whole chinook salmon, may have been contaminated with copper and nickel. This sample had concentrations of copper and nickel 48 and 5 times greater, respectively, than the next most concentrated sample and was not used for these elements (Appendix J).

Statistical Analyses

Data sets were examined graphically to compare variances. Normality of data sets was determined using the Kolmogorov-Smirnov test. Non-normal data sets were log-transformed prior to statistical analysis.

Differences in element concentrations between pre- and post-rain sampling could have been due to differing turbidities between these groups of sites, with higher turbidity at post-rain sites in 1996, or other difference between the sites. To discern the importance of turbidity, we would normally use a covariance analysis to compare the group mean concentrations and elucidate the influence of turbidity, but post-rain data were insufficient for this analysis. We therefore compared the post-rain data to the 95% prediction intervals from a pre-rain regression of element concentrations on turbidity (Neter et al. 1996). If the post-rain data fell within these prediction intervals, i.e., those data "fit" the pre-rain regression line, we concluded that observed differences between the pre- and post-rain sites were likely due to differences in turbidity, rather than other site differences. Alternatively, if post-rain data fell outside the intervals, other site differences were more likely. These analyses were performed for aluminum, barium, iron, magnesium, manganese, and strontium, which all had significant pre-rain regressions with turbidity.

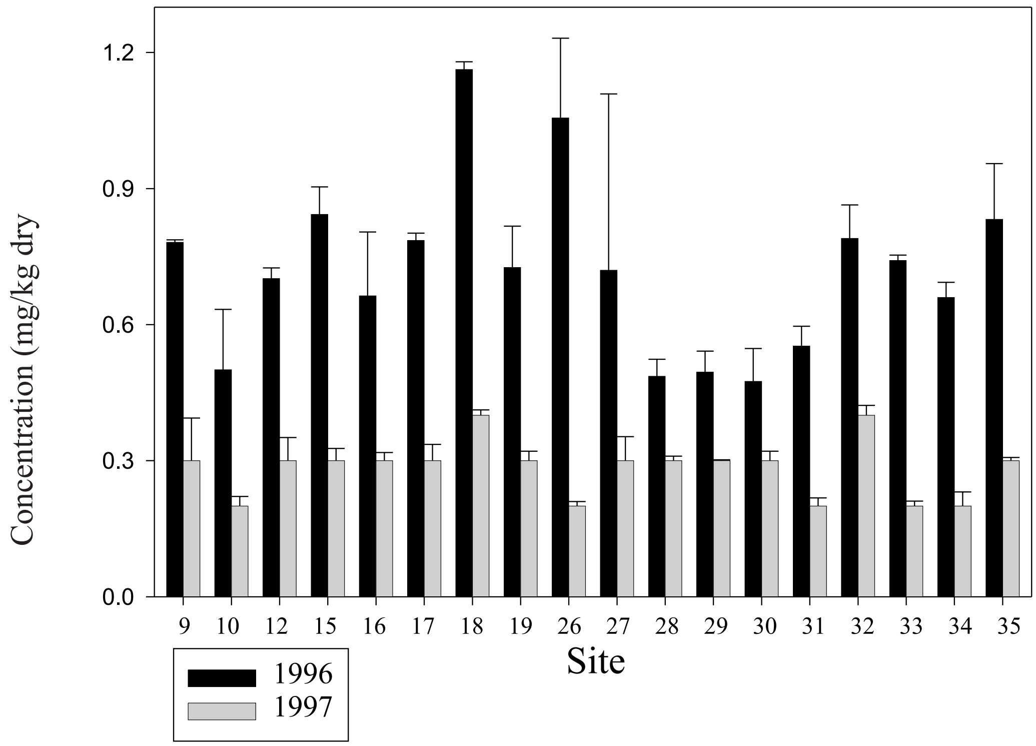

Figure 3. Mean cadmium concentrations and standard deviations in sediment from Innoko National Wildlife Refuge, Alaska, 1996-1997.

RESULTS

Water Quality

Mean values for water quality variables are presented in Tables 5, 6, and 7. Water quality measurements during 1995 were collected only at six sites in the upper Little Mud River drainage, off the Innoko Refuge, in conjunction with macroinvertebrate and fish collections. Water quality variables for 1995 and 1996 at the six sites were similar. Overall, turbidity was slightly greater for 1996, and although differences among all variables occurred between years, differences were not great and no patterns were discerned.

Several precipitation events during 1996 and 1997 may have affected water quality and trace element measurements. For both years, rain events were not uniform throughout the Refuge and watersheds were affected differently. For 1996, during the 30-day and 21-day periods prior to sampling, only 3 cm and 2.3 cm of rain were recorded at National Weather Service facilities in Galena, northeast of the Refuge and at McGrath, east of the Refuge (Figures 4 and 5), respectively. The rainfall event nearest in time to initiation of sampling was 0.38 cm on July 16, 1996, six days prior to sampling. From that time and through the first five days of sampling (July 22-26, 1996), no rainfall was measured or observed on the Refuge. During July 27-29, 1996, 3.7 cm, 4.6 cm, and 4.6 cm of rain, respectively, were measured at Galena. Thus, for water quality and water sampling purposes, the 1996 sample period was divided into pre-rain and post-rain periods. There was no major precipitation event affecting sampling in 1997, but sporadic small events occurred before and throughout the sample period. Three days prior to sampling in 1997, 7.4 cm of rain was reported at Galena and rain occurred intermittently on the Refuge during sampling; two rain events at the Innoko Refuge field camp, approximately in the center of the Refuge, yielded 1.5 cm and 0.6 cm of rain.

Table 5. Mean water quality variables (n = 2 samples/site) of streams near the Illinois Creek gold mine, Alaska, 1995.

Site	Site #	pH	Cond. (µS/cm)	Hardness (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Settleable Solids (mL/L)
UpperUpper California Creek	20	7.63	7.6383	39.6	36.4	0.6	0
Lower California Creek	21	7.57	80	37.7	33.4	1.1	Trace
Little Mud River[1] - Downstream	22	7.16	118	57.5	53.8	11	Trace
Little Mud River[1] - Upstream	23	7.26	88	48.1	43.8	8.7	Trace
Illinois Creek - Upstream	24	7.75	144	81.8	71.3	0.4	Trace
Illinois Creek - Downstream	25	7.76	150	78.4	68.3	0.9	Trace

[1] n = 1 sample/site

Table 6. Mean water quality variables (n = 3 samples/site) of streams within Innoko National Wildlife Refuge and near the Illinois Creek gold mine, Alaska, 1996.

Site Name	Site #	Date	Temp. (°C)	DO (mg/L)	pH	Cond. (µS/cm)	Hardness (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Settleable Solids (mL/L)	Suspended Solids (mg/L)
Tolstoi Creek	9	7/25/96	14	14	7.71	155	66	60	3	Trace	2
Madison Creek	10	7/25/96	13	14	7.54	138	55	55	5	0	3
Innoko River	12	7/30/96	11	12	7.56	98	46	39	29	0.7	153
No. Fork Innoko River	15	7/31/96	11	13	7.19	65	34	19	55		123
Finland Creek	16	7/30/96	6	12	6.85	32	21	13	37	1	387
Scandinavian Creek	17	7/30/96	6	12	6.91	37	20	12	79	1	410
Wapoo Creek	18	7/26/96	10	11	7.25	98	47	42	42	0.2	66
Lower Finland Creek	19	7/25/96	16	12	7.05	67	33	26	11	0	8
Upper California Creek	20	7/22/96	10	13	7.28	95	43	35	1	Trace	1
Lower California Creek	21	7/22/96	11	12	7.15	71	35	28	2	Trace	4
Little Mud River. - Downstream	22	7/22/96	14	11	7.33	83	40	34	19	0	11
Little Mud River- Upstream	23	7/22/96	14	12	7.13	82	40	40	20	0	12
Illinois Creek - Upstream	24	7/23/96	11	2	7.64	171	66	62	2	0	7
Illinois Creek - Downstream	25	7/22/96	12	14	7.82	141	70	64	3	Trace	4
Little Mud River	26	7/27/96	13	10	7.21	84	41	34	24	0.1	17
Dishna River	27	7/25/96	16	10	7.45	123	54	52	6	Trace	4
Big Mud River	28	7/26/96	11	10	7.21	135	39	49	67	0.4	247
Iditarod River	29	7/24/96	19	11	7.54	122	50	50	11	Trace	7
Big Yetna River	30	7/24/96	16	9	6.89	96	38	38	31	0	11
Little Yetna River	31	7/24/96	16	10	7.00	83	39	44	22	Trace	11
Galatea Creek	32	7/26/96	14	10	7.13	108	50	38	21	Trace	18
Moose Creek	33	7/24/96	17	11	7.53	98	45	44	13	0	6
First Chance Creek	34	8/1/96	6	12	7.12	46	27	18	52		120
Upper Magitchlie Ck.	35	7/27/96	15	10	7.25	149	68	64	11	Trace	5

Table 7. Mean water quality variables (n = 3 samples/site) of streams within Innoko National Wildlife Refuge, Alaska, 1997.

Site Name	Site #	Date	Temp. (°C)	pH	Cond. (µS/cm)	Hardness (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Settleable Solids (mL/L)	NH_3 (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)
Tolstoi Creek	9	7/8/97	15	7.49	149	73	62	2	Trace	0.01	0.7	0.01
Tolstoi Creek[1]	9	7/9/97		7.36	168	76	68	1		0.03	0.7	0.01
Madison Creek	10	7/8/97	15	7.51	207	101	91	8	0.0	0.08	1.1	0.01
Innoko River.	12	7/11/97	13	7.85	140	63	55	2	0.0	0.01		
No. Fork Innoko R.	15	7/11/97	13	7.61	115	55	52	30	0.5	0.14		
Finland Creek	16	7/11/97	11	7.76	148	67	59	4	Trace	0.01		
Scandinavian Creek	17	7/11/97	12	7.60	131	67	54	8	Trace	0.08		
Wapoo Creek	18	7/7/97	14	7.13	112	51	46	17		0.25	1.1	0.23
Lower Finland Creek	19	7/9/97	18	7.09	126	58	54	11	0.0	0.11	1.2	0.09
Little Mud River	26	7/10/97	14	7.01	105	48	40	18	0.0	0.21		
Dishna River	27	7/8/97	18	7.15	134	62	57	5	0.0	0.00	0.8	0.02
Big Mud River	28	7/10/97	12	7.18	154	75	61	18	0.0	0.18		
27 Iditarod River	29	7/6/97	22	7.16	130	62	57	11	0.0	0.05	0.5	0.05
Big Yetna River	30	7/6/97	16	6.91	83	32	33	41	0.3	0.19	0.9	0.47
Little Yetna River	31	7/6/97	18	6.96	99	38	43	16	Trace	0.09	0.8	0.59
Galatea Creek	32	7/7/97	17	7.02	110	52	42	15		0.19	1.5	0.44
Moose Creek	33	7/6/97	17	7.38	127	53	55	3	0.0	0.02	0.1	0.01
First Chance Creek	34	7/10/97	13	7.38	193	98	85	8	0.0	0.03		
Upper Magitchlie Ck.	35	7/9/97	19	7.09	168	84	76	6	0.0	0.16	1.6	0.80
Middle Magitchlie Creek	37	7/9/97	11	7.53	172	85	80	11	0.0	0.18	1.7	0.74

[1] n = 2.

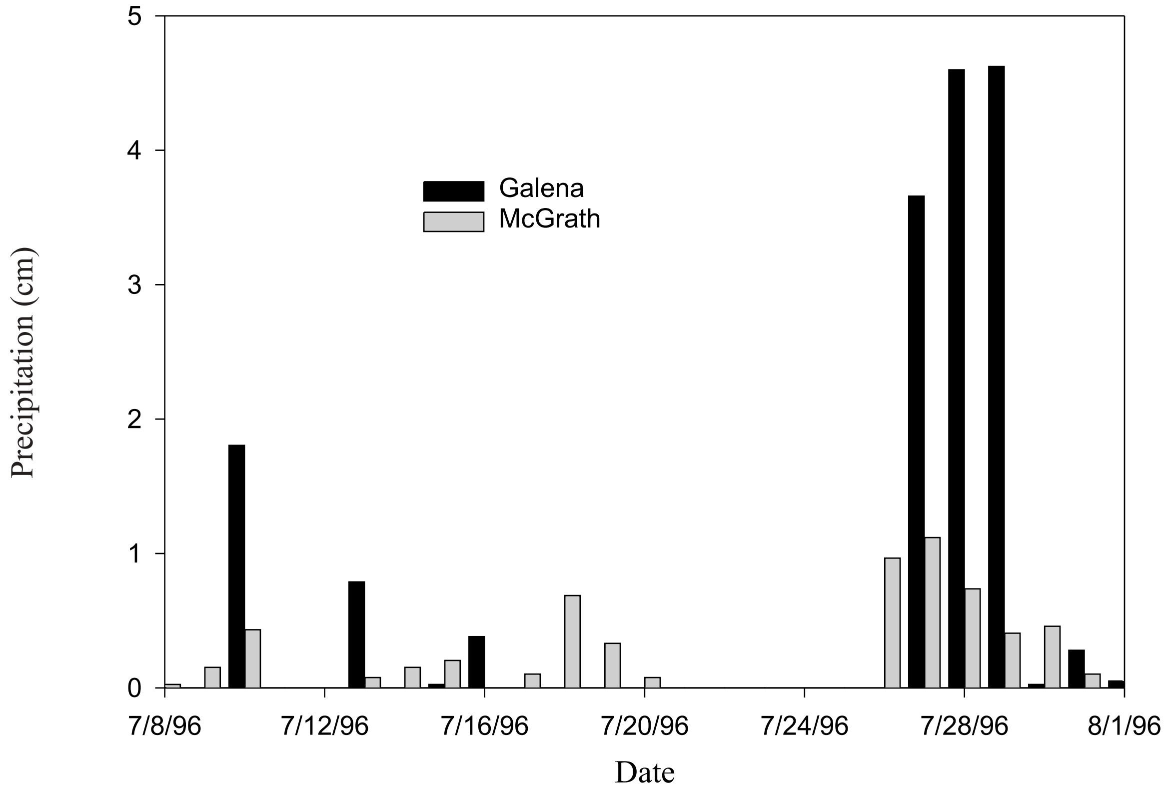

Figure 4. Precipitation at Galena and McGrath, Alaska two weeks prior to and during sampling (July 22 - August 1) at Innoko National Wildlife Refuge, Alaska, 1996.

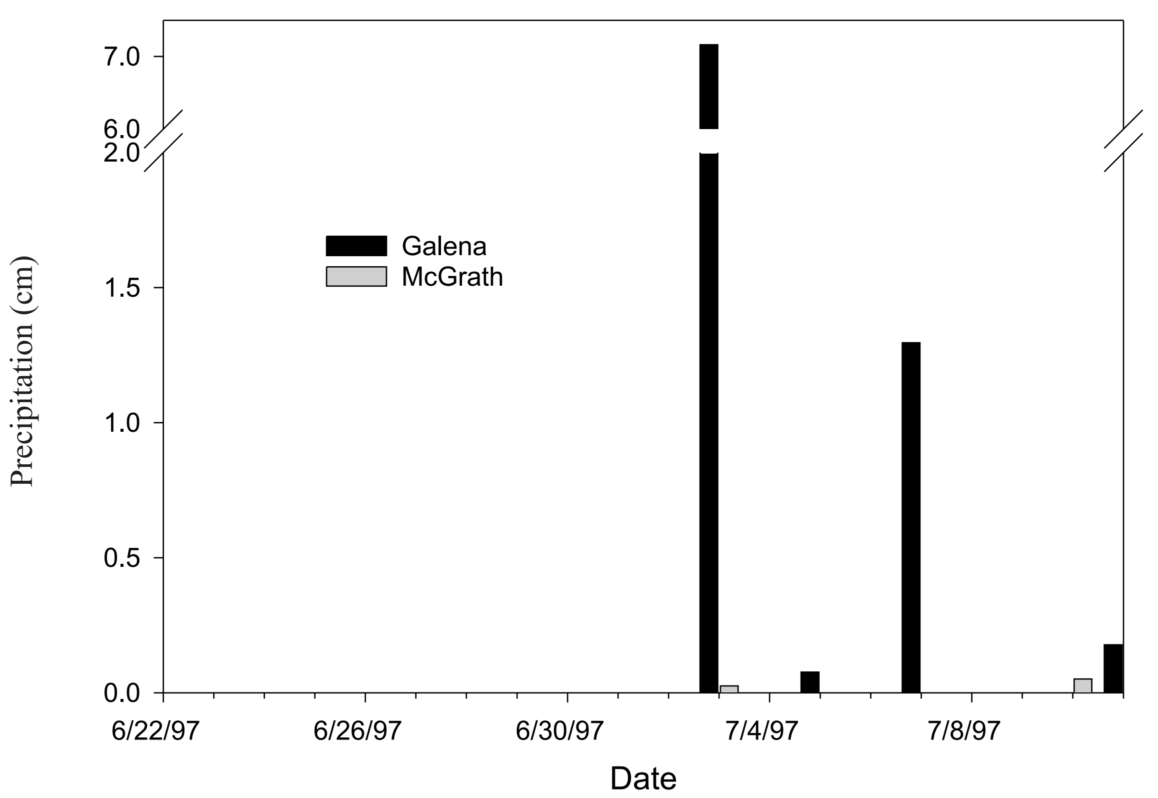

Figure 5. Precipitation at Galena and McGrath, Alaska two weeks prior to and during sampling (July 6 - 10) at Innoko National Wildlife Refuge, Alaska, 1997.

The effects of rain on water quality variables are illustrated by a comparison between sites sampled pre-rain and post-rain in 1996. All sites sampled during 1996 are pre-rain sites except Innoko River, North Fork Innoko River, Finland Creek, Scandinavian Creek, and First Chance Creek, which were sampled after the rain events. Significant differences occurred between pre-rain and post-rain sites for water quality variables for 1996 but not for 1997 ($P > 0.05$) (Table 8). The differences in water quality between years is presumably due to differences in precipitation patterns and volumes between years (Table 8).

Among samples with the lowest turbidity were those from California, Illinois, Tolstoi, Finland (1997) and Madison creeks, and the Dishna and Innoko rivers. For both years, streams north of the Innoko River, with the exception of Magitchlie Creek, were among streams with the greatest turbidity. These include the Big Mud and Little Mud rivers, Wapoo Creek, and Galatea Creek which had the lowest turbidity within this group. Big Yetna, Little Yetna, and North Fork Innoko rivers also had relatively high turbidities.

Table 8. Instances where concentrations of water quality variables were significantly greater at sites sampled either before (B) or after (A) rain events, Innoko National Wildlife Refuge, Alaska 1996. The same two sets of sample sites were compared for 1997.

Year	Hardness	Alkalinity	Conductivity	pH	Turbidity	Total Suspended Solids
1996	B [a]	B [b]	B [c]	B [d]	A [e]	A [f]
1997	NSD[g]	NSD	NSD	NSD	NSD	[h]

[a] $F_{4,59} = 36.4$, $P < 0.001$.
[b] $F_{4,59} = 57.8$, $P < 0.001$.
[c] $F_{1,23} = 11.9$, $P = 0.002$.
[d] $F_{1,68} = 4.3$, $P = 0.041$ for 1996.
[e] $F_{4,59} = 43.0$, $P < 0.001$.
[f] $F_{4,59} = 82.6$, $P < 0.001$.
[g] No significant difference in concentrations occurred ($P > 0.05$).
[h] No analysis was conducted.

Trace Elements in Water

Total Metals in Water

Mean values in samples for total metals in water are listed in Tables 9 and 10. Aluminum was detected in each sample for 1996 and in all but five samples for 1997 (Table 11). Barium, iron, magnesium, manganese, and strontium were detected in all samples. Arsenic was detected in each sample in 1997, but in a low percentage of samples in 1996, the result of a 1996 LOD more than an order of magnitude greater than for 1997. A similar situation occurred for boron, although to a lesser extent. The LODs of nickel for 1996 and 1997 were 0.0056 mg/L and 0.001 mg/L, respectively. Although there is not a great difference in these LODs, many detections for 1997 were 0.001 and 0.002 which accounts for the discrepancy in the percent detections between

Table 9. Mean total metal concentrations in water (mg/L, n = 3 samples/site), Innoko National Wildlife Refuge, Alaska, 1996.

Site	Al	As	B	Ba	Cr	Cu	Fe	Hg	Mg	Mn	Ni	Sr	V	Zn
Tolstoi Creek	0.086	<0.0056	0.023	0.043	<0.0056	<0.0056	0.56	<0.0003	6.57	0.07	<0.0056	0.068	<0.0044	<0.0111
Madison Creek	0.19	<0.0056	<0.0111	0.041	<0.0056	<0.0056	2.09	<0.0003	4.53	0.05	<0.0056	0.066	<0.0044	<0.0111
Innoko River	2.21	<0.0056	0.017	0.087	<0.0056	0.0069	4.24	0.000023	5.19	0.26	<0.0056	0.068	0.007	0.015
No. Fork Innoko River	3.11	<0.0056	<0.0111	0.100	0.005	0.0091	7.19	0.000012	3.58	0.16	0.0053	0.043	0.011	0.013
Finland Creek	8.37	<0.0056	0.011	0.153	0.011	0.0126	11.59	0.000048	3.66	0.28	0.0116	0.045	0.021	0.044
Scandinavian Creek	7.60	<0.0056	0.012	0.148	0.011	0.0161	11.20	<0.0003	3.83	0.29	0.0127	0.042	0.021	0.040
Wapoo Creek	1.31	<0.0056	0.014	0.057	<0.0056	<0.0056	5.36	0.0000078	3.66	0.22	<0.0056	0.046	0.005	0.013
Lower Finland Creek	0.45	<0.0056	0.013	0.036	<0.0056	<0.0056	3.30	<0.0003	2.78	0.07	<0.0056	0.037	<0.0044	<0.0111
Upper California Creek	0.08	<0.0056	<0.0111	0.009	<0.0056	<0.0056	0.26	<0.0003	3.67	0.02	<0.0056	0.035	<0.0044	<0.0111
Lower California Creek	0.13	<0.0056	<0.0111	0.011	<0.0056	<0.0056	0.47	0.0000083	2.58	0.02	<0.0056	0.032	<0.0044	<0.0111
Little Mud River - Downstream	0.32	<0.0056	<0.0111	0.025	<0.0056	<0.0056	2.52	0.0000023	3.16	0.08	<0.0056	0.041	<0.0044	<0.0111
Little Mud River - Upstream	0.33	<0.0056	<0.0111	0.027	<0.0056	<0.0056	2.62	<0.0003	3.06	0.09	<0.0056	0.043	<0.0044	<0.0111
Illinois Ck. - Upstream	0.22	0.014	<0.0111	0.008	<0.0056	<0.0056	0.30	<0.0003	7.47	0.01	<0.0056	0.019	<0.0044	<0.0111
Illinois Creek - Downstream	0.17	0.017	<0.0111	0.008	<0.0056	<0.0056	0.39	0.000011	8.00	0.02	<0.0056	0.024	<0.0044	<0.0111
Little Mud River	0.30	<0.0056	<0.0111	0.028	<0.0056	<0.0056	3.81	0.0000025	3.44	0.08	<0.0056	0.042	<0.0044	<0.0111
Dishna River	0.13	<0.0056	0.010	0.039	<0.0056	<0.0056	1.72	0.0000035	6.18	0.07	<0.0056	0.069	<0.0044	<0.0111
Big Mud River	5.25	<0.0056	0.012	0.179	0.0083	0.0109	10.54	<0.0003	7.51	0.23	0.0079	0.111	0.018	0.025
IditarodIditarod River	0.29	0.0048	<0.0111	0.046	<0.0056	<0.0056	4.38	0.0000066	5.11	0.16	<0.0056	<0.0056 0.074	<0.0044	<0.0111
Big Yetna River	0.38	<0.0056	<0.0111	0.041	<0.0056	<0.0056	6.26	0.0000023	3.35	0.13	<0.0056	0.046	0.005	<0.0111
Little Yetna River	0.37	<0.0056	0.014	0.034	<0.0056	<0.0056	5.34	<0.0003	2.63	0.07	<0.0056	0.065	0.005	<0.0111
Galatea Creek	0.32	<0.0056	<0.0111	0.039	<0.0056	<0.0056	4.04	<0.0003	4.68	0.11	<0.0056	0.043	<0.0044	<0.0111
Moose Creek	0.24	<0.0056	<0.0111	0.054	<0.0056	<0.0056	2.43	<0.0003	5.55	0.06	<0.0056	0.077	<0.0044	<0.0111
First Chance Creek	2.83	<0.0056	<0.0111	0.060	0.0059	0.0077	5.44	<0.0003	4.30	0.19	0.0084	0.031	0.008	0.015
Upper Magitchlie Ck.	0.21	<0.0056	0.016	0.062	<0.0056	<0.0056	5.15	0.000031	6.85	0.07	<0.0056	0.103	<0.0044	<0.0111

Table 10. Mean total metal concentrations in water (mg/L, n = 3 samples/site), Innoko National Wildlife Refuge, Alaska, 1997.

Site	Al	As	B	Ba	Fe	Mg	Mn	Ni	Sr
Tolstoi Creek	0.04	0.0007	0.0203	0.052	0.50	7.16	0.06	0.0017	0.08
Madison Creek	0.04	0.0009	0.0097	0.074	2.66	7.23	0.07	0.0010	0.12
Innoko River	<0.03	0.0009	0.0187	0.069	1.00	6.36	0.08	<0.001	0.09
No. Fork Innoko River	0.14	0.0012	<0.005	0.095	5.02	4.40	0.25	0.0020	0.07
Finland Creek	0.08	0.0011	0.0045	0.045	3.58	6.51	0.10	0.0017	0.07
Scandinavian Creek	0.13	0.0006	0.0037	0.038	1.08	5.44	0.07	<0.001	0.07
Wapoo Creek	0.65	0.0012	0.0074	0.053	4.08	4.25	0.22	0.0020	0.06
Lower Finland Creek	0.23	0.0035	<0.005	0.051	4.41	4.76	0.14	0.0020	0.07
Little Mud River	0.12	0.0030	<0.005	0.034	4.10	4.06	0.17	<0.001	0.05
Dishna River	0.09	0.0013	0.0123	0.047	1.68	7.14	0.07	0.0010	0.08
Big Mud River	0.37	0.0016	0.0053	0.085	4.97	7.34	0.15	0.0017	0.13
Iditarod River	0.49	0.0057	0.0080	0.068	5.57	6.06	0.33	0.0020	0.10
Big Yetna River	2.74	0.0032	<0.005	0.066	6.86	3.17	0.14	0.0020	0.05
Little Yetna River	0.52	0.0038	<0.005	0.043	6.05	3.24	0.06	0.0013	0.08
Galatea Creek	0.49	0.0035	<0.005	0.045	5.08	4.83	0.12	0.0033	0.05
Moose Creek	0.11	0.0004	0.0062	0.061	0.87	6.71	0.04	0.0010	0.10
First Chance Creek	0.14	0.0010	0.0137	0.037	2.49	13.17	0.11	0.0017	0.09
Upper Magitchlie Creek	0.12	0.0045	0.0103	0.070	5.13	7.53	0.15	0.0037	0.12
Middle Magitchlie Creek	0.48	0.0044	0.0098	0.087	5.68	7.29	0.10	0.0030	0.11

Table 11. Percent of water samples with metals detected in concentrations greater than the limit of detection from streams on Innoko National Wildlife Refuge, Alaska.

Year	n	Al	As[1]	B[1]	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
										Total Metals in Water										
1996	84	100	17	35	100	0	0	17	21	100	0	100	100	0	17[1]	1	0	100	32	26
1997	56	91	100	77	100	0	2	0	2	100	0	100	100	2	86	2	0	100	0	2
										Dissolved Metals in Water										
1996	44	100	25	16	100	0	0	0	0	100	0	100	100	0	0	0	0	100	0	7
1997	57	49	98	63	100	0	0	0	0	100	0	100	100	2	84	0	0	100	0	0

[1] - The low percent detection for these elements in 1996 compared to 1997 is due to a greater LOD in 1996.

the two years (Table 11). In 1996, chromium, copper, nickel, vanadium, and zinc were detected primarily in sites sampled after the rain event and the Big Mud River. Exceptions were vanadium near the LOD at Wapoo Creek, Big Yetna River and Little Yetna River, and zinc near the LOD at Wapoo Creek, Upper California Creek, Moose Creek, and Upper Magitchlie Creek. Beryllium, cadmium, and molybdenum were not detected in any samples for 1996 and 1997, except one detection each for cadmium and molybdenum at or near the LOD in 1997. Mercury was not detected at the LOD of 0.0003 mg/L for either year. In samples with a lower LOD (26 of the1996 samples), mercury was detected in concentrations up to 0.000050 mg/L.

Post-rain sites and the Big Mud River had most of the greatest concentrations of aluminum, barium, chromium, copper, iron, manganese, nickel, vanadium and zinc, and these concentrations were significantly greater than those from pre-rain sites in 1996 (Table 12 and Appendix J.1.). In 1997, these same sites, except the Big Mud River, typically had lesser concentrations of these metals than the median concentrations of all sites. For 1997, concentrations of aluminum, arsenic, and nickel were significantly greater in samples from pre-rain sites than from the post-rain sites (Appendix J.1.). The Big Mud River, for 1997, had concentrations of metals greater than the median concentrations of all sites for all analytes except boron.

For pre-rain sites in 1996, iron, magnesium, and manganese concentrations were correlated with pH ($r = -0.58$, 0.60, and -0.46; and $P < 0.001$, < 0.001, and $= 0.026$, respectively). Magnesium was also correlated with conductivity, hardness, and alkalinity ($r = 0.60$ to 0.87, all $P < 0.001$). Aluminum, barium, iron, manganese, and strontium were correlated with turbidity ($r = 0.76$ to 0.94, all $P < 0.001$, except strontium $P = 0.040$), but magnesium was not ($P = 0.85$). However, under higher turbidity conditions at post-rain sites, only aluminum and alkalinity were correlated in 1996 ($r = 0.15$, $P = 0.030$).

When comparing pre- and post-rain turbidity-metal relationships, all elements except magnesium were significantly associated with turbidity at sites sampled before the rain event ($P < 0.001$ for aluminum, barium and iron, and $P = 0.02$ for strontium). Post-rain manganese and strontium values were within the pre-rain 95% prediction intervals, indicating that differences in these metals between pre- and post-rain sites were caused by the increased turbidity after the rain event. However, aluminum and barium values were higher than, and iron values were lower than, the 95% prediction intervals, indicating that differences between the pre- and post-rain sites may be due to more than increased turbidity.

Dissolved Metals in Water

For 1996 and 1997, barium, iron, magnesium, manganese, and strontium were detected in every sample. Beryllium, cadmium, chromium, copper, mercury (at an LOD of <0.0003 mg/L), molybdenum (except one detection in 1997), nickel, lead, selenium, vanadium, and zinc (except three detections near the LOD in 1996) were not detected in any samples (Table 11). Aluminum was detected in each sample in 1996 but in only 49% of samples in 1997. The aluminum LOD of 0.03 mg/L for 1997, although near many concentrations measured in 1997, was less than all detections for 1996 where the LOD was at 0.0222 mg/L (Appendices E and G). Arsenic was

Table 12. Instances where concentrations of total and dissolved metals in water were significantly greater at sites sampled either before (B) or after (A) rain events, Innoko National Wildlife Refuge, Alaska 1996. The same two sets of sample sites were compared for 1997.

Year	Al	As	B	Ba	Cr	Cu	Fe	Mg	Mn	Ni	Sr	V	Zn
							Total Metals in Water						
1996	A	NSD [a]	NSD	A	A	A	A	NSE	A	A	NSD	A	A
1997	B	B	NSD	NSD			NSD	NSD	NSD	B	NSD		
							Dissolved Metals in Water						
1996	A	NSD	NSD	NSD			NSD	B	NSD		NSD		NSD
1997	NSD	B	NSD	NSD			B	NSD	NSD	B	NSD		

[a] No significant difference.

detected in 98% of samples for 1997 and only 25% of samples for 1996; the LOD for 1996 (0.0056 mg/L) was greater than all detections for 1997. Nickel was detected in 84% of all samples in 1997 but in no samples in 1996. As with total metals, most detections of nickel in samples from 1997 were very near the LOD of 0.001 mg/L which would not have been detected in the 1996 analyses with its greater LOD of 0.0056 mg/L.

Concentrations of dissolved metals at pre-rain and post-rain sites for 1996 did not follow the pattern of total metals. Three post-rain sites were sampled for dissolved metals in 1996; concentrations of metals at these sites were not consistently among the greatest of all samples, as with total metals, and were frequently less than the median concentrations of all sites combined. For 1996, aluminum concentrations were significantly greater after the rain event than before and magnesium was significantly greater before the rain than after (Table 12). Dissolved metals concentrations for the 1996 post-rain sites for 1997 were approximately evenly distributed around the median. In 1997, concentrations of arsenic, iron, and nickel were significantly greater at pre-rain (1996) sites than at post-rain (1996) sites (Appendix J.1.).

Prior to the rain events of 1996, dissolved aluminum, barium, iron, magnesium, and manganese were correlated with one or more water quality variables (all P   0.002). All of those metals, except magnesium, were correlated with turbidity (all $P < 0.001$). However, under higher turbidity conditions following the rain events, only dissolved aluminum and alkalinity were correlated $r^2 = 0.148$, $P = 0.030$), as with total metals.

In summary, 1996 water quality variables and metal concentrations were affected by a major precipitation event that occurred during the sampling period. Based on comparisons of sites sampled pre- and post-rain, precipitation increased turbidity, decreased pH, hardness, alkalinity and conductivity, and caused differences in total metal concentrations for some elements. These differences were not observed in 1997, which had a different precipitation pattern, for the same sets of sites. Post-rain sites and the Big Mud River had the majority of the greatest concentrations of aluminum, barium, chromium, copper, iron, manganese, nickel, vanadium, and zinc for 1996 but this was not true for 1997. In 1996, differences in manganese and strontium values between pre- and post-rain sites were caused by the increased turbidity after the rain event. Increased aluminum and barium values at post-rain sites may be due to increased turbidity and other factors. Concentrations of dissolved metals at post-rain sites for 1996 were not uniformly greater than at pre-rain sites, as were total metals. For total metals in water, barium, iron, magnesium, manganese, and strontium were detected in each sample for 1996 and 1997. Aluminum and arsenic were also commonly detected.

Trace Elements in Sediments

Mean metals concentrations from 1996 and 1997 are presented in Tables 13 and 14, respectively. All contaminant concentrations in sediment are expressed as mg/kg dry weight. Significant comments regarding concentrations and LODs of metals in sediment are contained in the Methods, Quality Assurance Quality Control and Laboratory Analysis section page 24.

Table 13. Mean metal concentrations (mg/kg dry weight) in sediments (n = 3 samples/site) from streams within Innoko National Wildlife Refuge and the upper Little Mud River drainage, Alaska, 1996.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe
Tolstoi Creek	15360	9.31	15.10	306	0.41	0.78	43.42	24.31	28249
Madison Creek	13290	4.04	11.05	181	0.35	0.50	28.44	15.24	21220
Innoko River	17557	9.94	13.53	285	0.40	0.70	34.45	25.52	25407
No. Fork Innoko River	18363	6.69	10.77	285	0.39	0.84	30.29	25.03	25214
Finland Creek	14170	7.71	9.13	189	0.54	0.66	21.43	13.96	19692
Scandinavian Creek	15900	4.93	9.13	219	0.36	0.79	24.46	23.29	22256
Wapoo Creek	21743	6.85	10.37	267	0.45	1.16	33.14	28.31	28879
Lower Finland Creek	14530	7.66	9.69	318	0.41	0.73	36.48	13.27	21571
Upper California Creek	16907	16.41	8.29	132	0.27	0.78	57.52	24.83	22574
Lower California Creek	15705	11.97	8.00	160	0.32	0.72	33.83	27.22	22528
Little Mud River - Downstream	18217	14.01	19.60	264	0.37	0.85	34.98	27.64	33251
Little Mud River - Upstream	14831	9.27	12.33	185	0.29	0.63	36.84	22.23	22423
Illinois Creek - Upstream	18931	26.48	13.47	141	0.37	0.81	52.11	24.50	24169
Illinois Creek - Downstream	15003	33.60	11.60	115	0.28	0.60	51.41	15.95	19112
Little Mud River	19305	15.84	16.40	274	0.39	1.06	35.90	25.86	32516
Dishna River	16331	9.69	17.10	241	0.51	0.72	59.26	20.62	29424
Big Mud River	18276	5.68	14.17	328	0.40	0.49	30.93	27.05	24087
Iditarod River	16079	13.69	19.90	233	0.41	0.50	42.95	18.96	30965
Big Yetna River	16104	7.31	16.97	290	0.44	0.47	33.62	15.01	25570
Little Yetna River	17587	7.04	16.97	235	0.49	0.55	27.75	14.17	26768
Galatea Creek	18326	10.68	16.07	259	0.38	0.79	31.74	25.11	26189
Moose Creek	14827	6.39	19.60	315	0.44	0.74	32.79	20.94	29273
First Chance Creek	13228	8.39	16.30	193	0.37	0.66	29.57	18.40	25706
Upper Magitchlie Creek	16419	5.41	16.53	310	0.44	0.83	32.17	24.57	25969

Table 13 Cont.

Site	Mg	Mn	Mo	Ni	Pb	V	Zn
Tolstoi Creek	7841	1603	<5.31	60.15	12.75	42.89	79.76
Madison Creek	4671	403	<5.31	18.59	10.76	41.21	55.10
Innoko River	6933	622	<5.31	30.92	14.23	45.32	81.64
No. Fork Innoko River	6030	474	<5.31	27.66	14.79	46.03	81.11
Finland Creek	3932	370	<5.31	17.64	13.90	34.26	61.18
Scandinavian Creek	5178	450	<5.31	23.71	13.21	40.96	72.52
Wapoo Creek	6220	363	<5.31	30.19	16.54	49.26	92.86
Lower Finland Creek	4905	419	<5.31	21.00	12.14	35.44	64.24
Upper California Creek	7043	475	<5.31	35.34	20.50	37.05	110.60
Lower California Creek	5021	348	<5.31	27.06	19.48	33.01	104.30
Little Mud River - Downstream	5572	465	<5.31	27.23	16.91	40.89	88.83
Little Mud River - Upstream	5134	700	<5.31	25.59	15.10	30.47	81.88
Illinois Creek - Upstream	6297	353	<5.31	29.78	21.88	47.03	88.45
Illinois Creek - Downstream	5898	267	<5.31	29.87	29.20	34.30	78.84
Little Mud River	5949	485	<5.31	28.58	16.40	43.99	90.52
Dishna River	8215	1057	<5.31	54.75	9.66	44.16	79.66
Big Mud River	5942	292	<5.31	26.40	13.13	53.67	68.40
Iditarod River	6839	506	<5.31	40.33	8.17	42.17	80.78
Big Yetna River	4180	280	<5.31	18.76	10.55	36.42	71.61
Little Yetna River	4671	374	<5.31	19.98	10.92	38.76	73.07
Galatea Creek	5642	410	<5.31	28.51	12.77	46.09	81.16
Moose Creek	5273	714	<5.31	43.33	10.03	38.27	80.56
First Chance Creek	4974	875	<5.31	36.21	10.18	38.43	79.19
Upper Magitchlie Creek	6446	517	<5.31	29.02	11.23	40.60	88.08

Table 14. Particle sizes and mean metal concentrations (mg/kg dry weight) in sediment (n = 3 samples/site) from streams in Innoko National Wildlife Refuge, Alaska, 1997.

Site	Clay (%)	Sand (%)	Silt (%)	Al	As	Ba	Be	Ca	Cd	Cu	Fe
Tolstoi Creek	11	53	36	13767	14.13	279	<0.688[a]	5293	0.34	26.67	29333
Madison Creek	10	33	57	14367	7.65	218	1.06	6063	0.23	24.40	29133
Innoko River	13	58	30	13363	14.28	316	<0.688[a]	4373	0.31	26.83	76633
No. Fork Innoko River	6	73	22	12133	17.23	302	0.72	3697	0.31	20.27	62000
Finland Creek	7	52	41	13933	10.30	207	<0.688	4830	0.33	24.07	33433
Scandinavian Creek	12	20	69	14733	11.40	203	1.03	5117	0.31	18.67	25033
Wapoo Creek	13	10	77	15600	7.86	206	1.30	3860	0.38	23.00	25100
Lower Finland Creek	14	23	63	16167	11.70	202	<0.688[a]	4403	0.27	19.77	26567
Little Mud River	10	62	28	11633	28.93	175	<0.688[a]	2813	0.23	16.17	50300
Dishna River	35	40	26	10047	32.87	280	<0.688	3783	0.30	18.43	136167
Big Mud River	14	8	78	18500	8.66	283	<0.688[a]	5087	0.27	27.43	29800
Iditarod River	19	13	68	20933	18.53	311	0.92	4700	0.26	24.20	35633
Big Yetna River	15	22	63	20867	10.47	267	<0.688[a]	4213	0.26	20.10	28100
Little Yetna River	15	15	70	16133	15.23	221	1.35	4447	0.24	15.00	28000
Galatea Creek	19	5	76	23033	12.40	293	<0.688[a]	4907	0.36	32.00	31133
Moose Creek	9	53	38	14133	6.95	260	1.04	3137	0.20	17.73	25867
First Chance Creek	9	36	55	13933	13.77	220	0.59	3240	0.22	20.80	46200
Upper Magitchlie Creek	16	7	77	16067	5.43	242	<0.688[a]	5147	0.29	17.43	25600

Table 14 Cont.

Site	Hg	Mg	Mn	Mo	Na	Ni	Pb	S	Se	Sr	Zn
Tolstoi Creek	0.14	6707	1613	<0.625	228	58.57	8.30	443	0.75	31.50	81.43
Madison Creek	0.09	4983	628	<0.625	210	19.07	7.69	398	0.32	33.73	69.73
Innoko River	0.12	4470	1433	1.05	199	23.47	7.93	578	0.71	31.50	76.40
No. Fork Innoko River	0.05	3630	1009	<0.625	144	19.00	7.88	415	0.32	26.53	66.57
Finland Creek	0.07	3833	1130	<0.625	211	19.93	8.32	380	0.42	27.50	84.87
Scandinavian Creek	0.10	3717	915	<0.625	276	21.33	9.47	372	0.40	29.23	71.33
Wapoo Creek	0.06	4327	486	<0.625	223	20.83	9.65	351	0.34	22.43	78.73
Lower Finland Creek	0.08	4450	437	<0.625	283	20.73	8.61	290	0.34	25.73	81.90
Little Mud River	0.04	3323	428	<0.625	123	16.53	10.78	388	0.28	16.57	60.47
Dishna River	0.12	4013	715	1.48	157	32.87	5.61	690	0.59	35.90	64.23
Big Mud River	0.06	5193	523	<0.625	235	24.27	9.64	364	0.39	35.00	78.07
Iditarod River	0.17	5333	893	<0.625	220	30.10	10.77	444	0.53	38.17	87.23
Big Yetna River	0.06	4483	652	<0.625	260	19.17	10.11	370	0.31	31.13	81.73
Little Yetna River	0.07	3987	722	<0.625	278	16.17	8.55	359	0.26	41.83	69.40
Galatea Creek	0.08	5490	580	<0.625	226	27.23	11.70	442	0.62	28.50	93.70
Moose Creek	0.07	4273	874	<0.625	151	34.30	6.91	264	0.39	31.47	73.67
First Chance Creek	0.25	4240	889	<0.625	188	29.30	7.48	408	0.41	25.60	78.90
Upper Magitchlie Creek	0.04	5313	386	<0.625	320	21.43	6.65	347	0.18	34.10	91.07

[a] One sample had concentrations >LOD.

The interannual variability seen in water measurements was also apparent in sediments. When data from all sites were grouped by year, concentrations of metals in sediments were significantly greater in 1996 for cadmium, magnesium, nickel and lead, and in 1997 for arsenic, iron and manganese (P = <0.001 to 0.029). Comparing sample sites by ranked metals concentrations allows a relative site comparison (Tables 15 and 16), but no one site was uniformly ranked high or low. For 1996, Madison Creek (Site 10) was consistently low for all metals, but it was more variable in 1997. Ranks for the Little Mud River (Site 26) for 1996 were diverse and generally in the upper half of concentrations, but during 1997, it had the lowest metals concentrations of any site (highlighted in Tables 15 and 16). For 1996, Finland Creek (Site 16) was low for many metals but highest for beryllium. For 1997, however, it had the lowest mean beryllium concentration. Among Refuge sites, Wapoo Creek (Site 18) generally had the greatest metals concentrations for 1996. Eleven of 25 sites in 1996 had all of the greatest concentrations of analytes and 10 of 18 sites in 1997 had all of the greatest mean metal concentrations. For example, Tolstoi Creek (Site 9) had the greatest mean concentrations of manganese and nickel for 1996, and magnesium, manganese, nickel, and selenium for 1997. Wapoo Creek had the greatest mean concentrations of aluminum, cadmium and copper for 1996; for 1997, Galatea Creek (Site 32) had the greatest mean concentrations of those metals and lead. In 1996, the six sites in the upper Little Mud River drainage (Sites 20-25, sampled only in 1996) had four of the six greatest concentrations of arsenic and zinc (the fifth for both metals was the Little Mud River at the Refuge boundary), and five of six for lead.

For 1996, three streams in the Little Mud River drainage were sampled at more than one site. Lower Illinois Creek had greater concentrations of all metals than upper Illinois Creek, except for nickel and selenium, which had comparable values, and lead. These two sites had the greatest concentrations of lead of all sites (Tables 13 and 15). Upper California Creek had greater concentrations of all analytes than lower California Creek except for barium, beryllium, and copper. Of the three sample sites on the Little Mud River, the most upstream site (Site 23) had the lowest concentrations of all analytes except chromium, where the three mean concentrations were very similar; manganese, where the upper site had much greater concentrations; and selenium, where the upper Little Mud River had the greatest concentrations among all sites sampled during 1996.

For 1997, the percentage of clay in samples was positively correlated with sulfur concentrations (r = 0.58, p = 0.001). Concentrations of aluminum were negatively correlated, and sodium positively correlated with percentages of sand and silt in samples (r = 0.60 and -0.61, for aluminum, and r = 0.61 and 0.68, for sodium, respectively; all P = <0.001).

For comparative purposes, sediment samples were divided into four groups based on stream location and size (Table 17), resulting in Off-Refuge, East, North, and South groups. Larger streams (Innoko, Iditarod, and Dishna rivers) were excluded from this analysis to make each group more homogeneous in stream size. Mining activities have occurred in some drainages in the Off-Refuge and East groups. There were significant multivariate

Table 15. Site numbers ranked in ascending order by mean metals concentration in sediment from streams within Innoko National Wildlife Refuge (site numbers 9-19 and 26-35), and the upper Little Mud River drainage (site numbers 20-25), Alaska, 1996. Site 26 (Little Mud River) is shaded as an example pattern.

Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Se	Sr	V	Zn
34	10	21	25	25	30	16	19	25	16	25	16	29	10	25	23	10
10	17	20	20	20	28	17	16	16	30	30	10	27	16	24	21	16
16	35	17	24	23	29	31	31	10	10	28	30	33	24	23	16	19
19	28	16	21	21	10	10	30	19	31	21	31	34	25	21	25	28
33	33	19	10	10	31	34	10	17	19	24	19	30	21	22	19	30
23	15	18	23	17	25	15	25	23	34	18	17	10	17	32	30	17
25	18	15	16	24	23	28	34	21	21	16	23	31	22	20	20	31
9	31	10	34	34	34	32	29	20	23	31	28	35	15	30	33	25
21	30	25	17	22	16	35	27	28	17	10	21	19	20	18	34	34
17	19	23	29	32	12	33	33	24	33	32	22	9	30	34	31	27
29	16	24	31	26	21	18	23	15	22	19	15	32	18	16	35	9
30	34	12	27	15	27	30	17	12	32	17	32	28	12	26	22	33
27	23	28	32	12	19	21	9	30	25	22	26	17	31	15	17	29
35	9	9	22	28	33	12	24	34	28	15	35	16	34	19	10	15
20	27	32	18	29	20	22	35	35	26	20	24	12	35	17	29	32
12	12	34	26	19	9	26	20	32	15	26	25	15	28	29	9	12
31	32	26	12	9	17	19	15	31	18	29	18	23	33	31	26	23
22	21	35	15	35	32	23	32	9	24	35	12	26	9	33	27	35
28	29	30	30	33	24	29	12	18	35	12	20	18	27	10	12	24
32	22	31	9	30	35	9	26	33	29	23	34	22	29	27	15	22
15	26	27	35	18	15	25	28	27	12	33	29	21	32	28	32	26
24	20	22	33	31	22	24	21	29	20	34	33	20	26	9	24	18
26	24	33	19	27	26	20	22	26	9	27	27	24	19	12	18	21
18	25	29	28	16	18	27	18	22	27	9	9	25	23	35	28	20

Table 16. Site numbers ranked in ascending order by mean metals concentration in sediment from streams within Innoko National Wildlife Refuge (site numbers 9-19 and 26-35), and the upper Little Mud River drainage (site numbers 20-25), Alaska, 1997. Site 26 (Little Mud River) is shaded as an example pattern.

Al	As	Ba	Be	Ca	Cd	Cu	Fe	Hg	Mg	Mn	Mo	Na	Ni	Pb	S	Se	Sr	Zn
27	35	26	16	26	33	31	17	26	26	35	9	26	31	27	33	35	26	26
26	33	19	27	33	34	26	18	35	15	26	10	15	26	35	19	31	18	27
15	10	17	26	34	26	35	35	15	17	19	15	33	15	33	35	26	34	15
12	18	18	28	15	10	33	33	18	16	18	16	27	10	34	18	30	19	31
9	28	16	9	27	31	27	19	30	31	28	18	34	30	10	31	10	15	10
16	16	10	34	18	30	17	31	28	27	32	19	12	16	15	28	15	16	17
34	30	34	32	30	29	19	30	31	34	10	26	10	19	12	30	19	32	33
33	17	31	15	12	28	30	10	16	33	30	28	16	18	9	17	18	17	12
10	19	35	19	19	19	15	9	33	18	27	29	29	17	16	16	28	30	28
17	32	33	12	31	35	34	28	32	19	31	30	18	35	31	26	33	33	18
18	34	30	29	29	27	18	32	19	12	33	31	32	12	19	10	17	9	34
35	9	9	30	16	15	16	16	10	30	34	32	9	28	17	34	34	12	9
31	12	27	17	32	17	29	29	17	10	29	33	28	32	28	15	16	10	30
19	31	28	33	28	12	10	34	12	28	17	34	30	34	18	32	29	35	19
28	15	32	10	17	16	9	26	27	35	15	35	17	29	30	9	27	28	16
30	29	15	18	35	9	12	15	9	29	16	17	31	27	29	29	32	27	29
29	26	29	35	9	32	28	12	29	32	12	12	19	33	26	12	12	29	35
32	27	12	31	10	18	32	27	34	9	9	27	35	9	32	27	9	31	32

Table 17. Significant differences in metal concentrations from sediment among North (N), South (S), East (E), and Off-Refuge (OR) groups of streams in and adjacent to Innoko National Wildlife Refuge, Alaska, 1996.

Group	Al	As	B	Ba	Be	Cr	Cu	Fe	Pb	V	Zn
North [a]	>S&E		>OR	>OR	>OR		>S&E	>OR	>S	>S,E&OR	
South [b]			>N&E	>OR	>OR			>E&OR			
East [c]					>OR						
		>N,S&E				>N,S&E			>N,S&E		>S&E

[a] Wapoo and Galatea creeks, and the Big Mud River.
[b] Big Yetna and Little Yetna rivers, and Moose and First Chance creeks.
[c] Tolstoi, Madison, Finland, and Scandinavian creeks.
[d] Illinois and California creeks.

differences among groups (Wilks = 0.00, $F_{45, 80}$ = 26.2, P = <0.001) with all metals except cadmium and nickel contributing. Manganese and magnesium did not have significant univariate group differences; all other metals did (Table 17). The Off-Refuge group was significantly different from other groups more often than any other group. The North, South, and East groups were not significantly different for arsenic, barium, beryllium, chromium, and zinc.

Trace Elements in Fish Tissues

Differences occurred in rates of detection and element concentrations between years, among tissues, and between species. For example, in 1996 (Table 18, Appendix K), mercury was detected in every sample, beryllium was detected in 3 of 14 muscle samples but in no kidneys or livers, and lead was undetected in all except one liver and all whole body samples. Boron was detected only in chinook salmon fry (which only were captured in California Creek in 1996) (Table 19). Vanadium was detected in one northern pike sample (liver), but in every Arctic grayling kidney sample. In 1997 (Table 20, Appendix M), arsenic, magnesium, mercury, selenium, and zinc were detected in every sample. Boron was detected only in northern pike muscle and only at the LOD of 1 mg/kg, which was greater than the LOD for 1996. Cadmium and vanadium were detected in most kidney samples, but in few muscle samples. Lead was detected in few samples (no whole body samples were collected in 1997).

Arctic grayling and northern pike muscle and kidney were sampled in both years, and were used to test for annual variation. Most comparisons (within species and tissue) were not significant, and of those that were, about half were greater in 1996 and half greater in 1997 (Table 21). However, arsenic concentrations were greater in 1997 for three of four comparisons (the final comparison was not significant).

Tissue concentrations were compared within species. Where significant differences occurred, kidney samples most often had greater metal concentrations than liver and muscle (Table 22). However, magnesium had significantly greater concentrations in muscle than in liver or kidney (Table 22).

When kidney and muscle concentrations were compared between species, approximately half of the comparisons were non-significant (Table 23). Of the significant comparisons, half were greater in Arctic grayling and half were greater in northern pike. Often, a particular metal was greater in one species compared to the other, for both tissues. For example, selenium was always greater in Arctic grayling compared to northern pike. Arsenic, mercury, and magnesium were greater in northern pike muscle compared to Arctic grayling (the kidney comparisons were not significant), and the greatest mercury concentration, 3.52 mg/kg, was in a northern pike muscle sample from the Iditarod pike hole (Site 36).

Table 18. Median and range of metals concentrations (mg/kg dry weight) in Arctic grayling (*Thymallus arcticus*) and northern pike (*Esox lucius*) from Innoko National Wildlife Refuge, Alaska, 1996.

Site	Species[1], Tissue[2]	n	As	Ba	Cd	Cu	Fe	Hg	Mg	Mn
Tolstoi Ck.	AG, K	5	0.4	1	0.52	4.45	720	0.5	757	3.1
			(<0.3-0.6)	(0.4-2)	(0.35-0.72)	(<4-7)	(360-1000)	(0.4-0.84)	(618-910)	(2-4.6)
Lower Finland Ck.	NP, K	1	0.4	4.9	0.92	4.2	522	1.1	744	3.3
Dishna R.	NP, K	1	<0.3	<1	<0.3	<10	620	0.38	1060	2
Upper Magitchlie Ck.	NP, K	1	<0.3	0.9	0.38	<4	350	0.2	868	3.3
Innoko Pike Hole	NP, K	6	0.2	1.1	0.325	5.35	475	2.05	770	2.9
			(<0.3-0.4)	(0.9-1.6)	(0.2-0.92)	(<4-7.7)	(350-683)	(0.2-2.7)	(690-1060)	(2-3.5)
Tolstoi Ck.	AG, L	5	0.45	0.095	0.23	4.4	226	0.31	728	6.9
			(<0.4-0.6)	(<0.06-0.34)	(0.2-0.3)	(3.9-5.1)	(103-368)	(0.3-0.5)	(619-759)	(4.5-10)
Lower Finland Ck.	NP, L	1	<0.4	0.1	0.28	35	2920	0.62	458	4
Dishna R.	NP, L	1	<0.5	<0.06	<0.1	9.6	157	0.21	630	4.2
Upper Magitchlie Ck.	NP, L	1	<0.4	<0.06	<0.1	13	300	0.07	440	2.2
Innoko Pike Hole	NP, L	6				30.5	650	0.70	440	2.2
			(<0.4)	(<0.06-0.61)	(<0.1)	(9.8-69)	(157-1030)	(0.45-1.5)	(324-719)	(1.2-5.3)
Tolstoi Ck.	AG, M	5	0.21	0.1		0.9	14	0.39	935	1.3
			(0.1-0.26)	(<0.06-0.64)	(<0.03)	(0.8-1)	(8.4-19)	(0.29-0.58)	(810-1150)	(0.93-4.3)
Lower Finland Ck.	NP, M	1	0.93	1.3	<0.03	<0.6	13	2.2	1370	2.9
Dishna R.	NP, M	1	0.3	0.3	<0.03	<0.6	10	0.75	1430	1.3
Upper Magitchlie Ck.	NP, M	1	0.59	0.44	<0.03	<0.6	7.6	0.29	1410	1.4
Innoko Pike Hole	NP, M	6	0.31	0.29		0.65	6.4	2.4	1400	1.6
			(0.21-0.37)	(0.07-1.1)	(<0.03)	(<0.6-1)	(6.3-13)	(0.61-3.5)	(1270-1450)	(0.54-3.4)

Table 18 Cont.

Site	Species[1], Tissue[2]	n	Mo	Ni	Pb	Se	Sr	V	Zn
Tolstoi Ck.	AG, K	5		0.73	0.09	15	1.4	5.3	82.5
			(<1)	(0.3-1.1)	(<0.03-0.14)	(13-20)	(0.88-3.3)	(5-10)	(79.2-87)
Lower Finland Ck.	NP, K	1	<1	0.97	<0.03	6.5	2.4	7.5	746
Dishna R.	NP, K	1	<3	<0.3	<.07	5.2	2.0	<10	282
Upper Magitchlie Ck.	NP, K	1	<1	0.57	<0.03	4.4	3.4	<4	778
Innoko Pike Hole	NP, K	6		0.2	0.05	5.8	0.88		799
			(<1)	(0.1-0.97)	(<0.03-0.13)	(4.4-6.8)	(0.73-3.4)	(<4-7.5)	(282-940)
Tolstoi Ck.	AG, L	5	0.4	0.2		6.8	0.38	0.8	69.6
			(<0.3-0.4)	(0.16-0.75)	(<0.04)	(6.3-10)	(0.29-0.89)	(<0.7-0.8)	(67.1-82.4)
Lower Finland Ck.	NP, L	1	0.4	0.16	<0.04	4	0.1	6.5	110
Dishna R.	NP, L	1	<0.3	0.48	<0.04	4.1	0.26	<0.8	163
Upper Magitchlie Ck.	NP, L	1	<0.3	0.3	<0.04	3.5	0.09	<0.7	76.6
Innoko Pike Hole	NP, L	6	0.6	0.09		4.8	0.09		101
			(<0.3-0.8)	(<0.9-0.45)	(<0.04-0.07)	(3.2-6.4)	(<0.07-0.26)	(<0.7)	(61.3-229)
Tolstoi Ck.	AG, M	5		0.06		1.3	0.82		14
			(<0.4)	(0.06-0.09)	(<0.04)	(1-1.8)	(0.66-0.93)	(<0.5)	(13-15)
Lower Finland Ck.	NP, M	1	<0.4	<0.04	<0.04	0.6	2.92	<0.5	14
Dishna R.	NP, M	1	<0.4	<0.04	<0.04	0.96	1.7	<0.5	20
Upper Magitchlie Ck.	NP, M	1	<0.4	0.09	<0.04	0.78	1.9	<0.5	15
Innoko Pike Hole	NP, M	6				0.63	1.4		14
			(<0.4)	(<0.04-0.05)	(<0.04)	(0.4-0.77)	(0.19-5.25)	(<0.5)	(13-17)

[1] AG = Arctic grayling (*Thymallus arcticus*), NP = northern pike (*Esox lucius*).
[2] K = kidney, L = liver, M = muscle

Table 19. Median and range of metals concentrations (mg/kg dry weight) in whole body samples of chinook salmon (*Oncorhynchus tshawytscha*) fry, silver salmon (*O. kisutch*) fry, and slimy sculpin (*Cottus cognatus*) from three sample sites in the upper Little Mud River drainage, Alaska, 1996.

Site	Species[1]	As	B	Ba	Cd	Cu	Fe	Hg	Mg
Upper California Ck.	CS[2]	0.5	7.6	3.2	0.055	2.9	85.8	0.15	1265
		(0.3-0.7)	(<1-9.9)	(2.3-4.4)	(<0.06-0.08)	(2.1-6.7[3])	(69.8-141)	(0.13-0.19)	(1170-1310)
Lower California Ck.	CS[4]	0.5	9.3	8	0.08	3.3	147	0.14	1330
		(0.4-1)	(6.3-10)	(6.5-9.0)	(0.06-0.11)	(3.3-6.7)	(124-190)	(0.12-0.16)	(1300-1340)
Illinois Ck. - Upstream	SS[4]	2		3.2	0.11	3	92.6	0.15	1380
		(0.94-3.3)	(<1)	(2.4-10.1)	(0.06-0.14)	(2.5-4.3)	(77.8-147)	(0.1-0.16)	(1290-1470)
Illinois Ck. - Upstream	S[5]	6.2		8.5	0.13	2.9	227	0.3	1740
		(3-13)	(<1)	(5.5-10.1)	(0.093-0.16)	(2.4-6.1)	(114-318)	(0.14-0.43)	(1730-1810)

Site	Species[1]	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Upper California Ck.	CS[2]	6.55	0.4	0.18	0.18	1.2	18.5		126
		(3.8-12)	(<0.4-0.4)	(0.1-2.6)	(0.07-0.76)	(0.92-1.5)	(15-23)	(<0.9)	(110-167)
Lower California Ck.	CS[4]	9.2	0.4	0.23	0.09	1.1	18.0		134
		(7.5-10)	(<0.4-0.4)	(0.22-0.33)	(0.08-0.1)	(0.69-1.3)	(16-22)	(<0.9)	(124-151)
Illinois Ck. - Upstream	SS[4]	7.2		0.26	0.28	0.99	12.5		153
		(7.1-21.7)	(<0.4-0.4)	(0.13-0.27)	(0.27-0.47)	(0.88-1.3)	(9.71-14.7)	(<0.9)	(114-168)
Illinois Ck. - Upstream	S[5]	23.9		0.51	0.48	3.6	30.2	1.5	198
		(23.8-29.3)	(<0.4-0.4)	(0.5-0.82)	(0.32-1.4)	(2.5-3.8)	(28.4-32.1)	(<0.9-2)	(114-218)

[1] CS = Chinook salmon (*Oncorhynchus tshawytscha*) fry, SS = silver salmon (*O. kisutch*) fry, S = slimy sculpin (*Cottus cognatus*).

[2] n = 14.

[3] One sample (321 mg/kg) had suspected contamination and was excluded.

[4] n = 5.

[5] n = 3.

Table 20. Median and range of metals concentrations (mg/kg dry weight) in Arctic grayling (*Thymallus arcticus*) and northern pike (*Esox lucius*) from Innoko National Wildlife Refuge, Alaska, 1997.

Site	Species[a], Tissue[b]	n	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe
Tolstoi Creek[c]	AG, K	5	8	0.4		0.3		0.50	1	3	892
			(<5-13)	(0.35-3.80)	(<1-<3)	(0.3-0.62)	(0.04)	(0.37-0.73)	(<0.8-1)	(2.6-3.4)	(792-1070)
Innoko River	AG, K	1	29	1.50	<1	2	<0.05	0.69	1	4.9	313
Finland Creek[c]	AG, K	1	10	1.40	<2	0.56	<0.05	0.59	<1	4.9	466
Scandinavian Ck.[c]	AG, K	1	<10.0	1	<4	0.4	<.08	1.60	<2	4	870
Dishna River	NP, K	1	78	0.43	<1	1.4	<0.05	0.65	0.8	5.1	481
Big Mud River	NP, K	1	24	0.53	<1	0.49	0.04	0.20	<0.8	3.8	272
Iditarod River[c]	NP, K	1	72	0.90	<2	2.2	0.09	0.92	<1	4.5	437
FirstFirst Chance Ck.	NP,NP, K	2	(13-21)	(0.53-0.59)	(<1.00)	(0.65-0.83)	(<0.05)	(0.43-0.62)	(1)	(3.4-3.8)	(450-516)
Innoko Pike Hole	NP, K	6	25	0.4		0.99	0.025	0.29	0.6	3.8	689
			(5-82)	(0.3-0.61)	(<1)	(0.58-1.8)	(<0.05-0.05)	(0.20-0.56)	(<0.8-0.7)	(3-4.3)	
Tolstoi Creek	AG, M	6		0.4		0.2				1.5	24
			(<5-17)	(0.3-0.4)	(<1)	(<0.1-0.3)	(<0.05)	(<0.1)	(<0.8-1)	(0.9-12)	(6-33)
Innoko River	AG, M	1	<5	0.5	<1	2.7	<0.05	<0.1	<0.8	<0.5	6
Finland Creek	AG, M	1	<5	0.4	<1	<0.100	<0.05	<0.1	<0.8	1	10
Scandinavian Ck.	AG, M	1	<5	0.4	<1	0.2	<0.05	<0.1	<0.8	0.7	6
Dishna River	NP, M	1	<5	0.3	<1	<0.100	0.1	0.20	1	<0.5	<4
Big Mud River	NP, M	1	<5	1.1	1	<0.100	<0.05	<0.1	<0.8	0.7	<4
Iditarod River	NP, M	1	5	0.99	1	0.64	<0.05	<0.1	<0.8	0.7	<4
First Chance Ck.	NP, M	2	6	0.066		0.37					
				(0.64-0.67)	(<1-1)	(0.2-0.54)	(<0.05)	(<0.1)	(<0.8)	(0.6-1)	(<4-5)
Innoko Pike Hole	NP, M	6		0.69	0.9					0.8	
			(<5-5)	(0.61-1.2)	(0.8-1)	(<0.1-0.2)	(<0.05)	(<0.1)	(<0.8)	(0.7-1)	(<4)

Table 20 Cont.

Site	Species[a], Tissue[b]	n	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
Tolstoi Creek[c]	AG, K	5	0.55	763	4	0.35	1.7		11	0.71	9.5	64.2
			(0.48-0.65)	(718-763)	(3.1-4.7)	(<0.6-<2)	(0.8-1.7)	(<0.4-<0.7)	(9.6-14)	(0.62-0.91)	(6.6-15)	(57.0-66.1)
Innoko River	AG, K	1	1.1	883	3.1	<0.6	0.9	<0.4	5.8	0.8	2.1	876
Finland Creek[c]	AG, K	1	0.35	947	3.2	<0.9	<1	<0.6	12	0.77	5.8	77.4
Scandinavian Ck.[c]	AG, K	1	0.48	774	3.8	<2	<2	1	11	0.61	9.7	83.8
Dishna River	NP, K	1	2.3	750	3	<0.6	1	<0.4	8	1.1	1.1	796
Big Mud River	NP, K	1	0.29	954	2.3	<0.6	<0.6	<0.4	4.9	1.2	1.4	498
Iditarod River[c]	NP, K	1	0.36	879	3.4	<1	<1	<0.6	5.7	1.8	2.1	1060
First Chance Ck.	NP, K	2	(0.22-0.31)	(646-837)	(2-2.1)	(<0.6)	(<0.6)	(<0.4)	(5.0-5.7)	(0.66-1.1)	(0.6-1)	(396-580)
Innoko Pike Hole	NP, K	6	2	694	2				4.8	1	0.8	892
			(1.7-3.72)	(681-772)	(2-4.2)	(<0.6)	(<0.6)	(0.4)	(3.6-5.4)	(0.8-7.7)	(<0.6-1)	(654-1060)
Tolstoi Creek	AG, M	5	0.43	1130	2				2.2	1		14
			(0.37-0.49)	(1070-1220)	(1-4)	(<0.6)	(<0.6)	(<0.4)	(1.9-2.7)	(0.7-1)	(<0.6)	(11-16)
Innoko River	AG, M	1	2.25	1400	4.3	<0.6	<0.6	<0.4	1.4	6.5	<0.6	17
Finland Creek	AG, M	1	0.24	1070	2	<0.6	<0.6	<0.4	2.2	0.9	<0.6	22.9
Scandinavian Ck.	AG, M	1	0.35	1290	2	<0.6	<0.6	<0.4	1.9	1	<0.6	16
Dishna River	NP, M	1	3.34	1410	<1	<0.6	0.9	1.9	1.9	<0.5	<0.6	13
Big Mud River	NP, M	1	0.63	1400	<1	<0.6	0.7	<0.4	1.1	0.7	<0.6	14
Iditarod River	NP, M	1	0.70	1380	<1	<0.6	<0.6	<0.4	1.2	2.4	<0.6	14
First Chance Ck.	NP, M	2	(0.55-0.73)	(1420-1430)	(<1)	(<0.6)	(<0.6)	(<0.4)	(1.5-1.7)	(1-2.6)	(<0.6)	(14-17)
Innoko Pike Hole	NP, M	6	3.44	1360					1.1	0.7		15
			(2.80-5.80)	(1320-1460)	(<1-1)	(<0.6)	(<0.6)	(<0.4-0.4)	(1-1.2)	(<0.5-2.1)	(<0.6)	(13-21)

[a] AG = Arctic grayling (*Thymallus arcticus*), NP = northern pike (*Esox lucius*).

[b] K = kidney, M = muscle.

[c] Some analytes had high LODs due to low sample volume.

Table 21. Summary of significant differences between years in kidney and muscle metals concentrations from Arctic grayling (*Thymallus arcticus*) and northern pike (*Esox lucius*) from Innoko National Wildlife Refuge, Alaska, 1996-97 (MANOVA on log-transformed data, $P < 0.05$). A blank indicates that a statistical test was not conducted.

Species, Tissue	N	As	Ba	Cd	Cu	Fe	Hg	Mg	Mn	Se	Sr	Zn
Arctic Grayling												
Kidney	12	NSD[a]	96>97	NSD	NSD	NSD	NSD	NSD	NSD	96>97	96>97	96>97
Muscle	12	97>96			NSD	NSD	NSD	97>96	NSD	97>96	NSD	NSD
Northern Pike												
Kidney	17	97>96	NSD	NSD	96>97	NSD	NSD	NSD	NSD	NSD	NSD	NSD
Muscle	16	97>96			NSD	96>97	NSD	NSD		97>96	NSD	NSD

[a] No significant difference.

Table 22. Significant differences in concentrations of metals in kidney (K), liver (L), and muscle (M) from Arctic grayling (*Thymallus* 49*arcticus*) and northern pike (*Esox lucius*) from Innoko National Wildlife Refuge, Alaska, 1996-1997 (MANOVA on log-transformed data test, $P < 0.05$). A blank indicates that a statistical test was not conducted.

Species Year	N	As	Ba	Cd	Cu	Fe	Hg	Mg	Mn	Ni	Se	Sr	Zn
A. Grayling													
1996	15	NSD[a]	K>L&M	K>L[b]	K&L>M	K>L>M	NSD	M>L&K	L>K&M	K&L>M	K>L>M	K>L	K>L>M
1997	14	NSD[a]	NSD	K>M	K>M	K>M	K>M	M>K		K>M	K>M	M>K	K>M
N. Pike													
1996	18	M>K	K>L&M	K>L[b]	L>K>M	K&L>M	NSD	M>K>L	K>M	K&L>M	K&L>M	K>L>M	K>L>M
1997	21	NSD	K>M	K>M	K>M	K>M	NSD	M>K	K>M	NSD	K>M	NSD	K>M

[a] No significant difference.

[b] Muscle data were not included in the statistical analysis; all cadmium analyses for muscle were <LOD; n = 10 for Arctic grayling, n = 12 for northern pike.

Table 23. Significant differences in metals concentrations of kidney and muscle tissue between Arctic grayling (AG) (*Thymallus arcticus*) and northern pike (NP) (*Esox lucius*) from Innoko National Wildlife Refuge, Alaska, 1996-1997 (MANOVA on log-transformed data, $P < 0.05$). A blank indicates that a statistical test was not conducted.

Tissue, Year	N	As	Ba	Cd	Cu	Fe	Hg	Mg	Mn	Ni	Se	Sr	V	Zn
Kidney, 1996	11	NSD[a]	NSD	AG>NP	NSD	NSD	NSD	NSD	NSD	AG>NP	AG>NP	NSD		NP>AG
Kidney, 1997	18	NSD	NP>AG	NSD	NSD	AG>NP	NSD	NSD	AG>NP		AG>NP	NSD	NSD	NP>AG
Muscle, 1996	11	NP>AG	NSD		NSD	NP>AG	NP>AG	NP>AG	NSD	AG>NP	AG>NP	NSD		NSD
Muscle, 1997	17	NP>AG			NSD	AG>NP	NP>AG	NP>AG		NSD	AG>NP	NSD		NSD

[a] No significant difference.

Chum Salmon

Two (from the Chena River collection) of 40 pairwise tests of linkage disequilibrium were significant between different genotypes at each microsatellite locus (Spearmen et al. 2002). Overall tests for these locus pairs across all collections were significant when the Chena River collection was included, but not when it was excluded. Significant differences in allele frequency distributions were detected between the Tanana and Innoko river collections but not within collections. Overall tests for differences in allelic frequencies across all collections were not significant. Significant differences in distribution frequencies of the five mtDNA haplotypes observed were not detected. Pairwise genetic distance trees, produced using mtDNA data, did not cluster collections within drainages. Pairwise genetic distance trees, produced using microsatellite data, clustered Tanana River collections but not Innoko River collections.

Coho Salmon

Among the differences in allele frequencies between Innoko and Tanana river collections was One 3*184 which occurred at over 20% in Innoko River collections and less than 3% in Tanana River collections (Spearman et al. 2002). Nine mtDNA haplotypes occurred among the collections, six in each of the Illinois and California creek collections, however, only three haplotypes were in both collections, two were in the Nenana collection, and the Clearwater collection was fixed for haplotype BAAB. All tests of linkage disequilibrium were nonsignificant. For mtDNA and microsatellites, 39% and 3% to 8% of total genetic variation was due to genetic differences among collections, respectively. Tests of heterogeneity showed significant differentiation among all collections. One of four tests for the Illinois and California creek collections was highly significant, indicating differentiation within the Innoko River drainage. Three to four tests were significant for each comparison between Innoko and Tanana river drainages. Microsatellite and mtDNA genetic distances clustered the collections by geographic region. No gene flow occurred between the Innoko and Tanana river populations and restricted gene flow likely occurred between at least two populations within the Innoko River drainage.

DISCUSSION

The loading, fates and toxic modes of action of metals and metalloids in aquatic habitats are complex and dynamic processes. The fate of metals in the environment is primarily controlled by the physical and chemical properties of the compounds; the physical, chemical, and biological properties of the ecosystem; and the sources and rates of input of the metals to the environment (Rand et al. 1995). Lower molecular weight metals arrive in Arctic areas through both local and aerial sources (Skotvold et al. 1996) and possibly through transport in biota (Ewald et al. 1998). Local sources of metals in interior Alaska may include sewage treatment plant effluent, municipal runoff, mine effluent, aerial deposition from the petroleum and mining industries, and runoff and leachate from contaminated sites. Contaminants reach remote freshwater sites by being carried long distances in the atmosphere (Barrie et al. 1992), but knowledge of temporal trends and spatial distribution of airborne contaminants in arctic and northern regions has been limited by a scarcity of precipitation monitoring stations (Schindler et al. 1995). However, moss (*Hylocomium splendens*), which acquires its nutrients from air, from arctic Alaska contained concentrations of copper and lead resembling those from industrialized regions of Siberia and western Russia (Ford and Vlasova 1996). Lake sediments frequently contain contaminants in concentrations several orders of magnitude greater than those of overlying waters, and appear to be good temporal records of contaminant deposition (Schindler et al. 1995). Modern fluxes of mercury to the Arctic, based on dated sediment cores, have been estimated to exceed pre-industrial fluxes by as much as seven-fold (Gobeil and Cossa 1993). Landers et al. (1995) reported a similar surface enrichment for mercury in Alaska. Mercury concentrations determined from dated cores from Arctic lakes in Canada and Finland showed widespread and continued input of mercury into Arctic sediments due to aerial transport (Lockhart et al. 1995; Mannio 1996; Dietz et al. 1998). Similarly, concentrations of other metals (e.g., cadmium, copper, lead, and zinc) have been shown to decrease with depth in lake sediment, with the greatest concentrations within the top 5 cm of sediment (Mannio 1996). Mercury concentrations in some arctic biota are increasing (Jensen et al. 1997); concentrations in peregrine falcons from Alaska may be increasing (Ambrose et al. 2000).

Closely related species of aquatic invertebrates and members of individual populations may differ dramatically in their concentrations of metals (Rainbow 1996), but toxic effects of metals in aquatic invertebrates are seldom documented because invertebrate communities are seldom monitored as extensively as fish. Bioconcentration factors experimentally determined for arsenic in invertebrate aquatic organisms are relatively low with little or no bioaccumulation occurring (Eisler 1988b). Cadmium and copper are the most toxic metals for freshwater invertebrates, whereas zinc is only mildly toxic to invertebrates (Timmermans 1993). Given the low monitoring effort and the high variability of aquatic invertebrate populations, effects of chronic exposure to metals contamination such as changes or retardation of life cycles or effects on predator-prey interactions are not often documented in the field.

Long, cold seasons, long life spans, and low growth rates may all contribute to high biomagnification factors, particularly for mercury and organochlorines, in arctic fish.

Biomagnification factors average over ten-fold per trophic level at northern sites, considerably higher than at more southerly sites (Schindler et al. 1995). In general, toxicity of metals for fish is most pronounced at elevated water temperatures, reduced pH, in soft waters, for younger life stages, and after long exposures (Eisler 1988a). Fortunately, Innoko Refuge waters do not have reduced pH or elevated water temperatures.

Water Quality

Water quality data are valuable for characterizing waterbodies and for evaluating other aquatic-based data; however, due to daily and seasonal variations, comparisons of water quality data collected during different time periods can be used for discussion of general trends only. Results from 1996 present a good opportunity to examine the effects of rain events on water quality and total metal concentrations in water. Rain caused an obvious difference in discharge and water quality in streams on the Refuge, with significantly greater turbidity after the rain, and significantly greater pH, conductivity, hardness and alkalinity before the rain. These are predictable results. Rainwater typically contains fewer dissolved solids than stream water because it has not had contact with rock or mineral soil which contain solutes. Rainwater dilutes the existing dissolved solids in stream water resulting in lower conductivity, hardness, and alkalinity. Similarly, rainwater typically has a lower pH than surface water, causing the resultant mix of surface water and rainwater to be more acid. The decrease in alkalinity, i.e., the buffering capacity of water, allows changes in pH to occur more easily. An increase in turbidity after a rain should be expected due to flushing of particulate matter from terrestrial sources and resuspension of aquatic sediments due to increased discharge. It is interesting to note that although several metals and water quality variables were significantly correlated before the rain, only aluminum and alkalinity were correlated after the rain events, and then for both total and dissolved aluminum.

The circumneutral pH values measured at Innoko Refuge and the upper Little Mud River drainage are typical of interior Alaska streams. In studies at other interior Alaska refuges, pH values ranged from approximately 6.5 to 8.5 (Snyder-Conn et al. 1992a,b; Mueller et al. 1993; Mueller et al. 1995; Mueller et al. 1996). Measures of dissolved solids in water (conductivity, hardness, and alkalinity) show that stream water in Innoko Refuge and the upper Little Mud River drainage are within the range typical of surface waters in interior Alaska (Mueller et al. 1995; Mueller et al. 1996). For example, mean values of hardness ranged from 20 mg/L to 101 mg/L in 1995-1997 at Innoko Refuge and vicinity, whereas values at other interior Alaska refuges ranged from 10 mg/L to greater than 200 mg/L (Snyder-Conn et al. 1992a,b; Mueller et al. 1993; Mueller et al. 1995). Hardness values in the Innoko Refuge area are in the ranges defined as soft and moderately hard by Hem (1992). In general, the bioavailability and toxicity of some metals, e.g., copper, cadmium and lead, are greater in conditions of low pH, low buffer capacity (i.e., low alkalinity), and low concentrations of divalent cations (Eisler 1985, 1988a; Environment Canada 1994). Because the toxic effect of divalent metals is somewhat attenuated by the presence of divalent cations, as measured by the hardness test, organisms inhabiting low hardness streams, as is the case for Innoko Refuge, are more susceptible to injury from metals contamination.

Trace Elements in Water

Water quality is not a consistent predictor of metals concentrations, as demonstrated by the changing relationships between metal concentrations and water quality variables associated with the rain event of 1996. Pre-rain iron, magnesium, and manganese concentrations were correlated with pH; magnesium was correlated with conductivity, hardness, and alkalinity; and aluminum, barium, iron, manganese, and strontium were correlated with turbidity. However, under higher turbidity post-rain conditions, only aluminum and alkalinity were correlated even though many metals concentrations and dissolved solids measures were greater than under pre-rain conditions. Concentrations of total copper, iron, manganese, nickel, and zinc were highly correlated with turbidity, and concentrations of total aluminum, iron, and manganese were highly correlated with turbidity and suspended solids at Kanuti National Wildlife Refuge (Mueller et al. 1995). Moore and Ramamoorthy (1984) reported that particulates contain 12-97% of the copper, 47-72% of the lead, 97-98% of the nickel (Yukon River data), and 10-78% of the zinc transported by rivers.

When we compared metals concentrations in waters from Innoko Refuge to regulatory criteria, including U.S. Environmental Protection Agency (EPA) Water Quality Criteria (WQC) for dissolved metals in water (USEPA 1999), proposed drinking water standards for the State of Alaska, and Canadian Water Quality Guidelines (Canadian Council of Resource and Environment Ministers 1987), we found that, in general, surface waters in and upstream of Innoko Refuge were relatively uncontaminated by metals. For example, no dissolved metals concentrations exceeded the EPA s WQC. To further characterize the condition of Innoko Refuge waters, we compared our Innoko Refuge data to data from other refuges in Alaska, including Koyokuk (Snyder-Conn 1992a), Nowitna (Snyder-Conn 1992b), Kanuti (Mueller et al. 1995), and Selawik (Mueller et al. 1993) (Table 24), and to published toxicity threshold levels. Specific metals are discussed below.

Aluminum

Aluminum concentrations in water were greater at Innoko Refuge for both sample years (discounting the 1996 post-rain samples) than at Koyukuk and Nowitna refuges (Snyder-Conn 1992a,b) but less than at Kanuti Refuge (Mueller et al. 1995) (Table 24). The mean value of 1.87 mg/L for Innoko Refuge during 1996 is high due to high concentrations of aluminum at rain-impacted sites.

Arsenic

Although no samples exceeded the EPA chronic WQC for arsenic, mean total arsenic at the Iditarod River for 1997 (0.0057 mg/L) and at both sample sites on Illinois Creek (1996 only) (0.014 mg/L, and 0.017 mg/L) exceeded the proposed drinking water standard for the State of Alaska of 5 µg/L (0.005 mg/L). This standard was also exceeded in one of three samples at Finland Creek and the Big Mud River, in two of three samples at the Iditarod River for 1996, and in one sample at Middle Magitchlie Creek for 1997. Concentrations near the drinking water standard for 1996 were undetectable because the LOD was 0.0056 mg/L. The LC20 for As^5

Table 24. Mean, range, and percent detections of total metals concentrations in water from Kanuti, Innoko, Nowitna, and Selawik National Wildlife Refuges, Alaska. Concentrations are expressed as mg/L.

Site	Year	Variable	Al	As	Ba	Be	Cd	Cr	Cu	Fe
Innoko	1996	Mean	1.87		0.0692					5.26
		Range	0.080-9.011	<0.0056-0.018	0.028-0.18	<0.0006	<0.0006	<0.0056-0.012	<0.0056-0.018	0.55-12.44
		%>LOD	100	7	100	0	0	26	33	100
Innoko	1997	Mean	0.481	0.0029	0.061					4.35
		Range	0.087-2.78	0.00039-0.006	0.0369-0.10	<0.0005	<0.0001-0.0002	<0.003	<0.007-0.0071	0.85-6.91
		%>LOD	100	100	100	0	3	0	3	100
Kanuti	1995	Mean	1.40						0.0092	3.11
		Range	0.06-2.92	<0.005-0.009			<0.001-0.002	<0.022	<0.01-0.031	0.4-30
		%>LOD	100	25			33	0	94	100
Koyukuk	1992	Mean	0.15				0.0019	0.0048	0.0047	1.41
		Range	0.020-0.388	<0.0005-0.0025	<0.020-0.04	<0.002	<0.0002-0.006	<0.002-0.007	0.0012-0.804	0.093-7.29
		%>LOD	100	50	47	0	87	89	100	100
Nowitna	1992	Mean	0.047	0.0021					0.0069	1.42
		Range	<0.015 -0.15	0.0006-0.0028		<0.001	<0.0001-0.0005	<0.002	0.0022-0.013	0.016-5.1
		%>LOD	73	100		0	5[a]	0	74	100
Selawik	1993	Mean					0.0028	0.0098		0.54
		Range				<0.002-0.006	<0.002-0.008	0.006-0.014		<0.15-1.66
		%>LOD				42	75	100		66

Table 24 Cont.

Site	Year	Variable	Mg	Mn	Ni	Pb	Se	Sr	V	Zn
Innoko	1996	Mean	4.63	0.14				0.060		
		Range	2.59-7.69	0.045-0.33	<0.0056-0.014	<0.011-0.012	<0.0056	0.031-0.11	<0.0044-0.023	<0.011-0.045
		%>LOD	100	100	26	2	0	100	50	39
Innoko	1997	Mean	6.77	0.13	0.0021			0.092		
		Range	3.13-13.2	0.043-0.35	0.001-0.004	<0.01	<0.002	0.040-0.13	<0.007	<0.006-0.0061
		%>LOD	100	100	100	0	0	100	0	3
Kanuti	1995	Mean		0.086	0.013	0.034				0.017
		Range		0.02-0.46	0.002-0.12	0.002-0.082				<0.01-0.087
		%>LOD		100	100	100				88
Koyukuk	1992	Mean	1.83	0.030	0.0035	0.043		0.028		0.017
		Range	0.30-4.02	0.004-0.04	<0.0018-0.008	<0.007-0.19	<0.0004-0.0004	0.009-0.0.068	<0.0002-0.012	<0.005-0.11
		%>LOD	100	100	75	70	14	100	22	97
Nowitna	1992	Mean		0.10		0.0022				
		Range		0.032-0.18	<0.0018-0.01	<0.001-0.0032				<0.0001-0.013
		%>LOD		100	7	75				33
Selawik	1993	Mean								
		Range								<0.03
		%>LOD								0

[a] LODs were 0.001 to 0.0001 mg/L for different years but only data from year with the lower LOD were cited.

(arsenate) versus the stonefly (*Pteronarcys dorsata*) was reported as 0.97 mg/L, and LC50s for chum salmon and rainbow trout embryos were reported as 11mg/L and 0.54 mg/L As^3 (arsenite), respectively (Eisler 1988b). In laboratory flow-through bioassays, fingerling rainbow trout showed reduced survival at sodium arsenate concentrations in water of 36 mg/L (Jarvinen and Ankley 1999). Arsenate is the predominant form of arsenic under oxygenated conditions with basic pH, but arsenite is generally considered to be the more toxic form (Eisler 1988b).

Cadmium

The greatest reported concentration of cadmium at the cited refuges was at Selawik Refuge (0.008 mg/L) (Mueller et al. 1993). Cadmium was detected in one sample at Innoko Refuge near the LOD of 0.0002 mg/L for 1997. Environment Canada (1994) reported that the range of cadmium in surface waters in Yukon Territory was <0.0001 to 0.0013 mg/L, and for Northwest Territories <0.0001 to 0.0154 mg/L. A lowest-observed-effect-level of 0.00015 mg/L $CdCl_2$ has been established for *Daphnia magna* (Biesinger and Christensen 1972).

Chromium

In the current study, chromium was not speciated into chromium III and chromium IV as it is expressed in the EPA s WQC; however, no total chromium concentrations exceeded the WQC for chromium III, the predominant form. Detection limits varied among other Interior Alaska refuges; detections of total chromium at the Koyukuk Refuge were generally close to the LOD of 0.002 mg/L, and less than the LOD of 0.0056 mg/L for 1996 at the Innoko Refuge. Total chromium was not detected at the Innoko Refuge for 1997, nor at the Kanuti and Nowitna refuges at LODs of 0.003 mg/L, 0.022 mg/L and 0.002 mg/L, respectively.

Copper

The greatest concentrations of total copper among all refuges was 0.80 mg/L at the Koyukuk Refuge, however, that datum was an outlier compared to the greatest Innoko Refuge value (0.0177 mg/L) at the post-rain sites and the Big Mud River (Table 24). Dissolved copper concentrations in uncontaminated freshwaters usually range from 0.0005 to 0.001 mg/L, increasing to 0.002 mg/L in urban areas (Moore and Ramamoorthy 1984). Dissolved copper concentrations at Innoko Refuge were all undetected at LODs of 0.0056 mg/L (1996) and 0.007 mg/L (1997). LaPerriere et al. (1985) reported that total recoverable copper ranged from 0.037 to 0.170 mg/L from a mined watershed in Alaska. Other refuges listed generally had higher rates of detections than at Innoko Refuge, especially in 1997, likely due to a slightly greater LOD (0.007 mg/L) at Innoko Refuge for that year.

Iron

Mean dissolved iron concentrations exceeded the chronic WQC (USEPA 1986) of 1.0 mg/L and the Canadian guideline for the protection of freshwater aquatic life of 0.3 mg/L total iron (Canadian Council of Resource and Environment Ministers 1987) in all Innoko River drainage waters measured except Tolstoi Creek, Illinois Creek, and California Creek. Iron was detected in every sample from every refuge, except at Selawik Refuge which is likely the result of a high LOD. The greatest mean iron values were at Innoko Refuge. Total iron concentrations found on Innoko Refuge were much greater than those at the Selawik, Koyukuk and Nowitna refuges, but within the range of values measured at the Kanuti Refuge (Table 24). High iron concentrations can impair wildlife health and reproduction. A total iron concentration of <3.0 mg/L is safe for growth and reproduction of the amphipod *Gammarus minus* (Sykora et al. 1972); however, Goettl and Davies (1977) observed 100% mortality by rainbow trout (*Oncorhynchus mykiss*) eggs when exposed to 3.4 mg/L and 2.2 mg/L iron within three and six weeks, respectively. Death appeared to be caused by flocculated iron compounds smothering the eggs and sac-fry. No adverse effects were observed when rainbow trout fry were exposed to 3.4 mg/L iron for five months (Goettl and Davies 1977). Iron hydroxide precipitate interferes with respiration through the chorion in fish eggs, and impairs gill function by occlusion of the lamellae (Sykora et al. 1972). Total iron concentrations are likely the relevant values, rather than dissolved iron concentrations, if smothering of eggs is the mode of death and biologic uptake in later life stages is not involved. Concentrations of total iron at Innoko Refuge sites frequently exceed those that cause mortality in rainbow trout eggs (Goettl and Davies 1977).

Manganese

Total manganese was detected in concentrations greater than the WQC (USEPA 1986) for domestic water supplies (50 µg/L) at many sites on Innoko Refuge but not at Illinois and California creeks. The criterion was set at 50 µg/L to prevent unwanted color and taste in public drinking water supplies, rather than as a toxicity threshold. Mean manganese concentrations at Innoko Refuge were greater than at Kanuti, Koyukuk, and Nowitna refuges although the range of concentrations was greatest at Kanuti Refuge (Table 24). There are few studies of manganese toxicity in freshwater communities.

Nickel

Nickel concentrations at Innoko Refuge were within the range of those at Kanuti, Koyukuk and Nowitna refuges, and all concentrations at Innoko Refuge were less than the EPA WQC (USEPA 1999). Nickel is less toxic to aquatic plants than other metals except lead and zinc. Significant reductions in growth and photosynthesis generally occur at 0.1-0.5 mg/L, far greater than concentrations observed at Innoko Refuge. Nickel is one of the least toxic heavy metals to invertebrates and fish, again, at concentrations far greater than those measured at Innoko Refuge (Moore and Ramamoorthy 1984).

Lead

Lead concentrations at Innoko Refuge were not high but evaluation is hindered by high LODs of 0.0111 mg/L (1996) and 0.01 mg/L (1997). Concentrations of total lead exceeded the EPA chronic WQC (USEPA 1999; 0.0025 mg/L dissolved lead at a hardness of 100 mg/L) in one of three samples at Scandinavian Creek for 1996 (0.0117 mg/L) and Finland Creek for 1997 (0.01

mg/L). Dissolved lead was undetected. However, because the LOD for dissolved lead was greater than the chronic WQC, some exceedences could have been missed. Lead concentrations were greatest at the Koyukuk Refuge but varied among refuges. Lead is neither essential nor beneficial to living organisms and no significant biomagnification of lead occurs in aquatic food chains. Lead is toxic to all phyla of aquatic biota and the responses of aquatic species to lead insult differ widely (Eisler 1988a). Eisler (1988a) noted that, among sensitive species, dissolved lead is more toxic than total lead, and effects are most pronounced at elevated water temperatures, in conditions of reduced pH, in soft waters, for younger life stages, and for long exposures. For the stonefly *Pteronarcys dorsata*, no effect on survival was noted at a concentration of lead nitrate of 0.565 mg/L and a whole body concentration of 0.340 mg/L wet weight (Jarvinen and Ankley 1999). At a hardness of 54 mg/L, comparable to those at Innoko Refuge, the LC50 of total lead for *Daphnia magna* was 0.612 mg/L (Eisler 1988a). For brook trout (*Salvelinus fontinalis*) at a water hardness of 44 mg/L, reduced growth has been reported at a total lead concentration of 0.134 mg/L (Eisler 1988a), and reduced reproduction at 0.235 mg/L (unknown hardness; Jarvinen and Ankley 1999). It is unlikely that lead toxicosis is occurring at Innoko Refuge because the effects of lead are significantly modified, in this case reduced, by biological and abiotic factors such as low water temperatures, circumneutral pH, and, for total lead, adherence to particulates (Eisler 1988a).

Zinc

Many sample analysis results for zinc from Innoko Refuge were <LOD. LODs from Kanuti and Koyukuk refuges were similar to those from Innoko Refuge but those refuges had much greater percentages of samples with concentrations >LOD (Table 24) indicating that, in general, concentrations of zinc at those refuges were greater than at Innoko Refuge. Eisler (1997) states that reproductive impairment seems to be one of the more sensitive indicators of stress due to zinc in freshwater teleosts with effects as low as 0.050 mg/L. Mean zinc concentrations at Finland and Scandinavian creeks for 1996 were 0.044 mg/L and 0.040 mg/L, respectively, approaching that value.

Integrated Comparisons

Jefferies and Carey (1994) reported mean values for metals in 11 rivers in Arctic Canada including cadmium (<0.2 µg/L), copper (<1-2 µg/L), lead (<0.7-1.3 µg/L), mercury (<0.2 µg/L), and zinc (<1-2 µg/L). Samples from post-rain sites and the Big Mud River exceeded these values for copper and zinc during 1996, but not for cadmium for 1997 (the LOD in 1996 was greater than the Canadian data) or mercury for 1996, the only year for which the LOD was low enough for comparison. Comparison of these figures with pre-rain samples for 1996 is limited by high LODs from our study.

Jackson (1990) conducted a baseline study of water, sediment, and tissue on Innoko Refuge during 1987 and 1988. Water and sediment data from that study reported here (Tables 25 and 26) are from sample sites similar in location to ours. In general, concentrations of total metals

Table 25. Mean metals concentrations (mg/L) in water from Innoko National Wildlife Refuge, Alaska, 1987-1988. From Jackson (1990).

Site	Year	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Tolstoi Creek	1988	0.16	<LOD[a]	0.002	0.008	0.003	0.38	0.03	0.010	0.02	0.021
Madison Creek	1988	0.09	<LOD	<LOD	0.007	0.002	1.15	0.03	<LOD	0.02	0.033
Innoko River	1987	2.05	0.0018	<LOD	0.004	<LOD	2.90	0.06	0.014	<LOD	0.007
Innoko River	1988	0.61	<LOD	<LOD	0.005	0.002	0.96	0.03	0.004	<LOD	0.034
Dishna River	1987	0.23	0.0015	<LOD	0.004	<LOD	0.83	0.02	0.010	<LOD	0.009
Dishna River	1988	0.10	<LOD	0.004	0.003	0.003	1.13	0.03	0.006	<LOD	0.030
Mud River	1987	0.37	0.0013	<LOD	0.004	<LOD	2.98	0.04	0.010	<LOD	0.008
Mud River	1988	0.63	<LOD	0.002	0.005	0.003	4.38	0.06	0.010	0.01	0.028
Little Mud River	1987	0.25	0.0023	<LOD	0.003	<LOD	3.20	0.07	0.013	<LOD	0.008
Little Mud River	1988	0.23	<LOD	0.002	0.004	<LOD	3.60	0.09	0.009	<LOD	0.052

[a] - Limits of Detection (LOD) were not reported for any analyte.

Table 26. Mean metals concentrations (mg/kg dry weight) in sediment from Innoko National Wildlife Refuge, Alaska, 1987-1988.
61 From Jackson (1990).

Site	Year	As	Al	Sb	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Zn
Tolstoi Creek	1988	9.58	9887	<LOD[a]	<LOD	63.87	13.83	23433	19.4	1222	0.06	49.87	0.84	70.23
Madison Creek	1988	9.97	14967	<LOD	<LOD	47.87	8.33	29133	13.9	863	0.08	22.63	0.54	64.90
Innoko River	1987	6.36	12067	0.20	0.89	21.23	14.67	22267	<LOD	482	0.04	20.00	0.16	57.83
Innoko River	1988	13.37	15800	<LOD	<LOD	79.07	27.70	34667	21.6	757	0.12	37.87	0.73	95.70
Dishna River	1987	11.47	11433	0.28	<LOD	27.40	18.47	22067	<LOD	392	0.13	45.43	0.35	67.83
Dishna River	1988	8.80	8533	<LOD	<LOD	75.90	3.63	18533	17.1	1444	0.04	39.17	<LOD	52.27
Mud River	1987	7.59	13533	0.19	1.15	23.83	14.69	21200	<LOD	350	0.07	19.37	0.32	63.57
Mud River	1988	3.47	12060	<LOD	<LOD	73.07	11.70	30167	19.9	455	0.09	31.20	0.39	97.43
Little Mud River	1987	13.48	9527	0.19	1.17	18.53	9.33	21900	<LOD	383	0.06	13.24	0.26	41.27
Little Mud River	1988	8.43	4397	<LOD	<LOD	27.17	<LOD	13700	<LOD	199	<LOD	11.03	<LOD	26.27

[a] - Limits of Detection (LOD) were not provided for any analyte.

and total recoverable metals in water reported by Jackson (1990) are similar to the total metals results from our study, though several exceptions are notable. Jackson (1990) reported cadmium from 0.002 mg/L to 0.004 mg/L from four streams where we did not detect it at LODs of 0.0001 mg/L and 0.0006 mg/L. He detected nickel at each site except Madison Creek but we detected nickel in 1996 only at sites sampled after the rain, and at the Big Mud River. We detected nickel at all but three sites in 1997 but in concentrations between the LODs of 0.0056 mg/L and 0.001 mg/L for 1996 and 1997, respectively, an order of magnitude less than those reported by Jackson (1990).

Jackson (1990) reported total metals and total recoverable concentrations of metals in water in excess of action levels he defined for comparative purposes (Table 27) on nine creeks within the Refuge. He reported exceedences for aluminum, cadmium, chromium, copper, nickel, and zinc. Only one of Jackson s (1990) mean values, cadmium at the Dishna River (0.004 mg/L) exceeded the EPA WQC.

Table 27. Action levels produced by Jackson (1990) for waters of Innoko National Wildlife Refuge, Alaska and chronic U.S. EPA National Recommended Water Quality Criteria (1998) (mg/L).

	Cd	Cr	Cu	Ni	Zn
Jackson (1990)	0.003	0.03	0.01	0.3	20.0
USEPA (1998)	0.0022	0.074	0.009	0.052	0.12

Increased turbidity caused by the rain event of 1996 was responsible for increases in some total metals concentrations. For example, post-rain manganese and strontium values were within the pre-rain turbidity prediction intervals, indicating that increases in these metals were probably caused by the increased turbidity alone. However, aluminum and barium were higher, and iron was lower, than predicted based on turbidity alone, so other factors, such as differential size composition of turbidity-causing materials in the high-discharge environment, probably contributed to these differences. This is supported by the non-significant differences in dissolved metals concentrations at pre-rain compared to post-rain sites (dissolved metal samples have all particles > 0.45 µm removed prior to analysis).

In general, we found greater turbidity associated with greater metals concentrations. Concentrations of total metals in the aptly named Big Mud River were similar to those sampled after the rain events of 1996 even though it was sampled prior to the rain in 1996. The Big Mud River is naturally turbid, even at lower water levels, and its banks and sediment are composed of fine-grained material. Even though it was sampled prior to the rain of 1996, the Big Mud River had some of the highest turbidity values for that year and for 1997. Similarly, during both years, Wapoo Creek and the Big Yetna River had some of the greatest turbidity values and, in general, some of the greatest total metals concentrations.

Metal concentrations at some sites may have been great enough to affect fish. California Creek is located downstream of Illinois Creek within the Little Mud River drainage and is used by salmon for spawning and rearing. Concentrations of arsenic, cadmium, chromium, copper, mercury, vanadium, and zinc in California Creek were less than the LC50s of these elements to chinook salmon in environmentally relevant water qualities (Hamilton and Buhl 1990b). For 1996, copper concentrations at post-rain sites and the Big Mud River exceeded the LC50 for silver salmon at hardness of 88 mg/L (Sorensen 1991). For Arctic grayling and silver salmon, copper has been shown to account for >97% of the summed toxicity of a mixture of copper, zinc, lead and arsenic; the summed toxic units of the mixture showed less-than-additive toxicity (Buhl and Hamilton 1990). Total and total recoverable copper concentrations reported from five streams in Alaska with active placer mines had greater than the acutely toxic concentrations of these elements either individually or in mixtures (Buhl and Hamilton 1990).

Changes in fish behavior, especially avoidance reactions, are sensitive indicators of sublethal exposure to metals (Giattina et al. 1982; Atchinson et al. 1987). Mean concentrations of copper in the North Fork Innoko and Big Mud rivers, and First Chance, Finland and Scandinavian creeks were greater than concentrations shown in laboratory experiments to cause avoidance behavior in rainbow trout (Atchinson et al. 1987) and chinook salmon (Hansen et al. 1995). Similarly, zinc concentrations at these streams exceeded the lowest level threshold of 0.0056 mg/L given by Eisler (1997) for avoidance due to zinc. However, avoidance behavior is a complex response which may involve metal concentrations, organism acclimation, dissolved organic carbon concentration, and other factors, so the presence of concentrations of copper exceeding experimental thresholds does not in itself mean that fish avoidance should be expected to occur at these locations.

Trace Elements in Sediments

Tributaries of the Little Mud River likely drain mineralized areas such as those supporting the Illinois Creek Mine in the Illinois Creek drainage. The six sites in the upper Little Mud River drainage (Sites 20-25) accounted for four of the six greatest concentrations of arsenic and zinc (the fifth for both metals was the Little Mud River at the Refuge boundary), and five of the six greatest concentrations of lead in 1996, the only year those sites were sampled. Samples from Illinois Creek had the greatest concentrations of lead for all sites.

Just as water quality variables may affect metals concentrations in water, grain sizes may affect metals concentrations in sediment. For 1997, concentrations of aluminum, sodium, and sulfur were correlated with various grain size fractions. Metals concentrations at Koyukuk, Northern Unit of Innoko, and Nowitna refuges were not correlated with grain size fractions (those samples were not analyzed for sodium or sulfur) (Mueller et al. 1996).

The high variability of metals concentrations in sediment samples can affect interpretation of relative and actual concentrations. For example, we and Jackson (1990) observed variability between years in sediment metals concentrations. When data from all sites from Jackson (1990) were grouped by year, concentrations of chromium and iron in sediments were significantly greater in 1988 ($F_{2,12}$ = 19.7, P = 0.009 and 0.012, respectively), and concentrations of lead were significantly greater in 1987 ($F_{2,12}$ = 19.7, P = 0.029). For our data, cadmium, magnesium, nickel and lead were significantly greater in 1996, and arsenic, iron and manganese were significantly greater for 1997. Beryllium concentrations at Finland Creek and the Dishna River had the greatest mean values in 1996 (0.54 mg/kg and 0.51 mg/kg, respectively) but were <LOD (0.688 mg/kg) for 1997, less than all other sites. Why concentrations of beryllium increased at all sites but these two is unknown. Some sites for some elements had consistent concentrations between years. Tolstoi Creek had the greatest mean concentrations of manganese and nickel for both years, and the greatest and second greatest mean magnesium concentrations for 1996 and 1997, respectively. Further, when our 1996 data were compared to 1987 data from Jackson (1990), arsenic, iron, manganese, nickel, and zinc were not significantly different, but aluminum and copper were significantly greater from our study ($F_{9,21}$ = 19.8, P = 0.007 and 0.002, respectively), and chromium and lead were significantly greater ($F_{9,21}$ = 19.8, P < 0.001) from Jackson (1990). With only three samples per site in both our study and Jackson s (1990), it is likely that the observed variability between years is due to natural variability or insufficient sample size to account for the variability at each site.

Concentrations of metals in sediment at Innoko Refuge were within the range observed at other interior Alaska refuges except for arsenic, cadmium, iron, and manganese, which were greater (Table 28). One sample from upper Magitchlie Creek had 3.27 mg/kg beryllium, far greater than the <0.688 mg/kg for the other two samples at that site; sample contamination or analytical error is suspected as the cause of this discrepancy. All other beryllium results are within the ranges cited from other refuges. Cadmium concentrations at Innoko Refuge for 1996, up to 1.20 mg/kg, were greater than at any other refuge, but cadmium concentrations for 1997 were in the lower portion of the range for all refuges. Sediment samples from our study were within the range listed by Outridge et al. (1994) from areas with no known source of cadmium pollution (0.2 - 2.5 mg/kg). Iron concentrations were similar to those at the Kanuti Refuge (Mueller et al. 1995), although the maximum concentration from our study was slightly greater. The maximum concentrations of manganese for Innoko, Northern Innoko, and Nowitna refuges exceed the background and severe effect concentrations established by the Ontario Ministry of the Environment at 400 mg/kg and 1100 mg/kg, respectively (Persaud et al. 1992). Mean values for all refuges cited, except Kanuti Refuge (395 mg/kg), exceed this background concentration (Snyder-Conn et al. 1992a,b; Mueller et al. 1993; Mueller et al. 1995; Mueller et al. 1996).

Sediments from the off-Refuge group of streams were different from at least one other group for all elements compared except aluminum, boron, and copper. The Off-Refuge streams drain more highly mineralized and more headwater areas than the On-Refuge groups. The groups of streams with the most dissimilar sediments were the North and Off-Refuge groups (Table 17). The South and East groups of streams were the groups most similar to one another even though streams in the East group drain mineralized areas.

Table 28. Means, ranges, and percent detections of metals concentrations in sediment from Kanuti, Innoko, Koyukuk, Northern Innoko, Nowitna, and Selawik National Wildlife Refuges, Alaska. Concentrations are mg/kg dry weight.

Site	Year	Variable	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe
Innoko	1996	Mean	16522	8.18	14.38	262	0.42	0.72	33.82	21.09	26053
		Range	9329-23070	3.13-21.09	7.86-20.8	133-415	0.30-0.60	0.35-1.20	17.63-68.04	8.16-31.48	16567-35590
		%>LOD	100	100	100	100	100	100	100	100	100
Innoko	1997	Mean	15519	13.77		249		0.28		21.83	41335
		Range	7290-25100	4.46-49.70		164-375	<0.69-3.27	0.18-0.45		14.10-32.90	22400-166000
		%>LOD	100	100		100	48	100		100	100
Kanuti	1995	Mean		6.03[a]		46.00	0.19	<0.05	13.03	21.00	23186
		Range		2.40-13.40[b]		20.6-90.7	0.16-0.23	<0.05-0.64	11.1-16.7	4.20-36.2	6540-32333
		%>LOD		100		100	100	77 [c]	100	100	100
Koyukuk	1992	Mean		9.00			0.36		20.1	21.3	
		Range		5.23-13.7	<5.00-30.0[c]		0.1-0.81	<0.5-0.74	11.5-28.0	7.5-37.6	
		%>LOD		100			100	45	100	100	
No. Innoko	1996	Mean					0.41	0.59		36.21	
		Range			<5.00-11.3		<0.20-0.95	<0.20-1.12		25.1-43.4	
		%>LOD			50		78	89		100	
Nowitna	1992	Mean					0.75		46.7	23.8	
		Range					0.25-1.48		13.1-81.4	8.71-42	
		%>LOD					93		100	100	
Selawik	1993	Mean	24466	3.57		285				7.32	
		Range	4990-38800	2.04-6.34		66.40-491	<1.0-1.31			<5.0-13.70	
		%>LOD	100	100		100	17			83	

Table 28 Cont.

Site	Year	Variable	Hg	Mn	Ni	Pb	Se	Sr	V	Zn
Innoko	1996	Mean		567	30.87	12.30			42.11	76.75
		Range	<0.106-0.197	228-1623	12.05-63.81	7.01-18.14			27.75-55.76	41.69-107
		%>LOD	31	100	100	100			100	100
Innoko	1997	Mean	0.093	795	25.24	8.67	0.42	30.36		77.19
		Range	0.037-0.33	307-1990	14.6-65.6	4.43-16.6	0.17-1.2	15.6-42.3		48.9-99.4
		%>LOD	100	100	100	100	100	100		100
Kanuti	1995	Mean		395	23.72	6.71		55.9	16.46	63.22
		Range	<0.05-0.06	117-706	5.00-38.00	2.00-14.5		9.8-143	13.60-22.20	19.00-110
		%>LOD	44	100	100	100		100	100	100
Koyukuk	1992	Mean		432	22.67	13.68		51.92	29.48	60.14
		Range	<0.14	179-423	7.9-34.8	7.0-22.1		5.7-51.1	19.8-46.3	19-85
		%>LOD	0	100	100	100		100	100	100
No. Innoko	1996	Mean		683	47.31	13.89		26.24		99.27
		Range	<0.14	244-1500	33.1-86.0	7-25.7		11.6-40.9		62.6-133
		%>LOD	0	100	100	100		100		100
Nowitna	1992	Mean	0.9	601	32.5	11.68		38.0	97.24	79.6
		Range	0.05-1.74	200-1091	10.9-41.6	7.8-20.4	<0.96-2.17	9.7-103	20.3-182	31.3-158
		%>LOD	100	100	100	100	5	100	100	100
Selawik	1003	Mean							48.20	43.96
		Range	<0.02-0.04						26.80-71.00	25.90-62.00
		%>LOD	50						100	100

[a] A mean of mean values.
[b] A range of mean values.
[c] Many analyses had high LODs.

The variety of fish species and tissues analyzed in this study were chosen based on the distribution of fish species within the sample area, and because size, life history and trophic status can affect contaminant concentrations. Slimy sculpin and salmon fry are smaller than Arctic grayling and northern pike, so the former were analyzed as whole-body samples and the latter as tissues. However, because whole bodies are predominantly muscle, contaminant concentrations sometimes can be compared to muscle values in other species. Arctic grayling and northern pike are migratory species (Morrow 1980). Radio-tagged Arctic grayling have migrated up to 101 km from spawning or summer feeding areas to overwintering sites (West et al. 1992). Northern pike generally spend the winter in deepwater areas and in spring move upstream to spawning and summer feeding areas (Morrow 1980). Alt (1985) reported that northern pike generally do not migrate off of Nowitna Refuge by way of the Yukon River. On Kaiyuh Flats (Northern Innoko Refuge), Taube (1995) determined that radio-tagged northern pike remained in Kaiyuh Flats all year, overwintering in three areas which they left in March and early April bound for spawning areas. Slimy sculpin are sedentary, do not migrate and, therefore, can be more indicative of local conditions than other fish species. Slimy sculpin and salmon fry are primarily insectivorous, Arctic grayling are insectivorous and piscivorous, and northern pike are piscivorous.

Discussion by Taxa

We compared data from this study to the U.S. Fish and Wildlife Service/U.S. Geological Survey National Contaminant Biomonitoring Program (NCBP), designed to monitor contaminant concentrations in biota throughout the United States. From late 1984 to early 1987, 319 composite whole-body samples were collected from 109 sites throughout the United States as part of the NCBP (Schmitt et al. 1999). Collections were made at about half of the stations each year from 1976 through 1981 and the samples were analyzed for metals and metalloids. The data were expressed in wet weight; however, we transformed them to dry weight, assuming 75% moisture, for comparative purposes. Because these data are from whole-body specimens, we compared them to muscle and whole-body analyses only.

<u>Northern Pike</u>

Concentrations of arsenic in northern pike muscle were within the range of, or less than, the 1996 NCBP geometric means (0.33 mg/kg - 0.80 mg/kg) except one 1996 muscle sample each from Lower Finland Creek (caught in the Innoko River) and the Iditarod River, and one 1997 sample from the Iditarod Pike Hole. The three exceptional samples were in the range of the NCBP 85th percentile range (0.88 - 1.52 mg/kg). Arsenic concentrations in northern pike were within to slightly greater than the range reported for muscle samples for muskellunge (*Esox masquinongy*) from New York, and whole-body northern pike samples from New York and Wisconsin (Jenkins 1980). Concentrations of cadmium, copper, lead, selenium, and zinc in northern pike muscle were less than the NCBP 85th percentile range except one sample from the Dishna River for lead. Cadmium in muscle, undetected for 1996 (LOD = 0.03 mg/kg), was lower than all NCBP mean concentrations, but the LOD of 0.1 mg/kg for 1997 was higher than preferred, so this comparison was not made. Concentrations of barium, cadmium, copper, iron, magnesium, manganese, nickel, and selenium in kidney were in the range of values from the Kanuti, Koyukuk, Nowitna, and Selawik refuges (Snyder-Conn et al. 1992a,b; Mueller et al. 1993; Mueller et al. 1995; Mueller et al. 1996). Zinc concentrations in kidney at Innoko Refuge were greater than from the Kanuti and Nowitna refuges.

Mercury is a toxic metal with no known essential function in vertebrate organisms (Wiener and Spry 1996). Aerial transport is a major anthropogenic source of mercury to interior and western Alaska streams and adjacent marine areas. Based on lake sediment core data, modern fluxes of mercury to northern Canada (Lockhart et al. 1995) and Alaska (Landers et al. 1995) exceed pre-industrial fluxes by as much as seven-fold. Accumulation of mercury from the medium by representative species of marine and freshwater teleosts and invertebrates is well documented (Eisler 1978, 1981). Dietz et al. (1998) listed four general trends for mercury in fish tissue in the Arctic based on analysis of archived northern pike muscle tissue from Sweden collected between 1968 and 1996: 1) the greatest concentrations of mercury tend to be in predatory fish (mercury bioaccumulates and biomagnifies [Guthrie et al. 1979]); 2) there is a tendency for mercury concentrations to correlate positively with length (age) for northern pike, but not for whitefish (*Coregonus* spp.) and Arctic char *(Salvelinus alpinus*); 3) the greatest concentrations of mercury in fish are not necessarily correlated with the presence of mercury concentrations in sediments even though sediment concentrations of mercury are increasing in Arctic areas; and 4) fish from Arctic Canada generally have the greatest body burdens of mercury found in the Arctic. Their final conclusion was based on very little data from Arctic Alaska; the definition of Arctic used by AMAP, the organization which published Dietz et al. (1998), includes Innoko Refuge. Mean concentrations of mercury in northern pike muscle samples from nine rivers and lakes in Yukon and Northwest territories, Canada ranged from 0.44 mg/kg to 2.5 mg/kg (assuming 75% moisture) (Muir et al. 1997), within the range of northern pike muscle samples from Innoko Refuge.

Factors associated with accumulation of high concentrations of mercury in fish include: piscivorous feeding habits, biomagnification of mercury in food chains, fish age and longevity, anthropogenic discharges of mercury to the environment, high water temperature, atmospheric deposition of mercury, and low acid-neutralizing capacity of surface waters (Wiener and Spry 1996). The fish and aquatic ecosystems of Innoko Refuge possess many of these factors. Lockhart et al. (1972) reported that northern pike taken from a lake heavily contaminated with methymercury and placed in a lake relatively free of mercury eliminated 30% of muscle mercury in one year.

Mercury in fish tissue is widespread throughout the United States (Schmitt et al. 1999). USEPA (1992) found mercury in fish tissue at 92% of 374 sites in the contiguous 48 states. The mean mercury concentration at what were considered background sites was 0.36 mg/kg (assuming 75% moisture) (USEPA 1992). The geometric mean values of all fish sampled in the NCBP ranged from 0.32 mg/kg to 0.35 mg/kg (Schmitt et al. 1999). Eight of nine northern pike muscle samples from Innoko Refuge exceeded the greatest NCBP geometric mean for mercury and five of eight exceeded the NCBP 85th percentile maximum value of 0.76 mg/kg. Mercury concentrations in northern pike kidney were similar to those at Kanuti and Selawik refuges (Mueller et al. 1993; Mueller et al. 1995) but less than those at the Nowitna Refuge (Snyder-Conn et al. 1992b). Headlee (1996) reported the mean concentration of mercury from 48 northern pike muscle samples from Kaiyuh Flats (Northern Innoko Refuge) to be 1.75 mg/kg (assuming 75% moisture) compared with 1.59 mg/kg from Koyukuk, Nowitna and Northern Innoko refuges (Mueller et al. 1996), and 1.82 mg/kg and 2.56 mg/kg from our study for 1996 and 1997, respectively.

Jackson (1990) measured metals concentrations in northern pike muscle at Innoko Refuge during 1987 (Table 29). Mean values of aluminum (15.3 mg/kg), iron (17.1 mg/kg), and mercury (3.42 mg/kg) were greater than for our 1996 (no aluminum) and 1997 data. Jackson (1990) apparently had a high LOD for copper, however, the values detected are all greater than our values for copper for 1996 and 1997. Arsenic, manganese, selenium, and zinc values from Jackson (1990) were similar to values from 1996 and 1997 from our study.

Arctic Grayling

Concentrations of arsenic, cadmium, copper, lead, selenium (1996 only), and zinc in muscle samples were within, or less than, the geometric mean concentration ranges of the NCBP. All values in muscle for these elements, as well as mercury, were less than the NCBP 85th percentile ranges. All but one selenium concentration in muscle for 1997 were between the greatest NCBP mean and the NCBP 85th percentile. Mean concentrations of cadmium, copper, nickel, lead, and zinc in liver from the Tolstoi River were less than or equal to the geometric mean of Arctic grayling liver from four lakes in Arctic Alaska (Allen-Gil et al. 1997). Although mean mercury concentrations in liver from Tolstoi Creek were within the range of those from the four lakes, mean mercury concentrations in muscle for 1996 and 1997 at Tolstoi Creek were greater than all geometric means from these lakes. Copper, nickel, and zinc in 1996 muscle samples from Tolstoi Creek were less than those from the four lakes; the mean copper concentration for 1997 was within the range of copper in muscle reported by Allen-Gil et al. (1997).

Salmon Fry

In general, juvenile life stages (fry) of silver salmon, Arctic grayling, and rainbow trout are more sensitive to injury from metals than the alevin life stage (Buhl and Hamilton 1991). Concentrations of arsenic were greater than the NCBP 85th percentile range in 1 of 19 chinook salmon collected (California Creek) and all 5 silver salmon collected (Illinois Creek). All silver salmon fry from our study had greater concentrations of arsenic than silver salmon muscle (adults) from Wisconsin and Lake Erie (up to 1.96 mg/kg) (Jenkins 1980).

Boron was detected in 17 of 19 chinook salmon fry in concentrations up to 10.0 mg/kg but not in silver salmon fry or Arctic grayling, and in only 5 of 19 northern pike muscle samples at the LOD of 1.0 mg/kg. We do not know if this is a result of differing conditions in the waterbodies or differing species. Hamilton and Wiedmeyer (1990) reported that, in toxicity tests, boron was

Table 29. Concentrations of metals in northern pike (*Esox lucius*) muscle from Innoko National Wildlife Refuge, 1987. Concentrations are mg/kg-dry weight calculated from wet-weight assuming 75% moisture. From Jackson (1990).

Site	Al	As	Cr	Cu	Fe	Hg	Mn	Se	Zn
Iditarod River	12.4	0.88	1.52	<LOD	14.4	4.4	2.68	1.04	14.8
Grouch Creek	20.4	0.84	2.28	<LOD	14.4	2.52	2.48	1	16
Unnamed Creek	12.8	0.48	2.52	1.32	18.8	4.4	1.48	1	13.2
Hather Creek	20	0.4	2.04	<LOD	23.2	1.92	1.6	0.68	16.4
LowerLower Mud Lower Mud River	15.6	0.28	1.84	<LOD	12	3.04	2	0.72	16.4
Dishna River	21.6	0.28	4.4	17.6	27.6	3.36	2.24	0.76	24.4
LowerLower Lower Tolstoi Lower Tolstoi Creek	18.4	0.36	2.4	9.6	31.6	2.88	1.28	0.72	20
Tolstoi Creek	14.4	0.16	1.4	3	14.4	2.52	0.72	0.52	16.8
Madison Creek	28.4	0.72	1.32	1.52	18.4	3.12	1.64	0.88	14.8
Hammer Creek	5.6	0.56	2.4	<LOD	12.8	6.8	1.52	1.24	16.8
Innoko River	8.8	0.88	1.12	<LOD	8.8	4.4	0.88	1.4	12.8
Innoko River	5.2	0.28	1.24	1.64	8.4	1.68	1.52	0.76	17.6

not detected in chinook salmon fry exposed to boron concentrations as high as 6.05 mg/L (more than two orders of magnitude greater than in streams we sampled) for up to 90 days but silver salmon, after a 283-h exposure to 0.33 - 0.66 mg/L boron, accumulated whole-body concentrations of 900 - 1,560 mg/kg (assuming 75% moisture) and perished (Thompson et al. 1976). Chinook salmon fingerlings exhibited poor growth and survival after accumulation of up to 200 mg/kg boron during 28 days of exposure to tile drainage from the San Joaquin Valley, however, other variables could not be excluded as potential contributors to the observed toxicity (Saiki et al. 1992). Boron is relatively non-toxic in water, but results from toxicity studies vary widely, possibly due to the different compounds of boron, fish species tested, and type of dilution water used (Hamilton and Buhl 1990a). Mean boron concentrations in water at California and Illinois creeks were <0.0111 mg/L. Mean concentrations of boron in surface waters of the U.S. have been reported as 0.01 µg/L (Forstner and Wittmann 1979) and 0.1 µg/L (Sprague 1972). Eisler (1990) recommends limits as low as 0.001 mg/L in water to protect sensitive aquatic life. Saiki et al. (1993) reported that boron does not bioaccumulate in aquatic food chains. Although mean sediment concentrations of boron were greater at Illinois Creek than at California Creek, boron was not detected in silver salmon fry from Illinois Creek.

Salmonids are very sensitive to selenium contamination. Chinook salmon fry from California Creek had up to 1.5 mg/kg and silver salmon from Illinois Creek had up to 1.3 mg/kg selenium. Hunn et al. (1987) reported that rainbow trout fry had significant mortality when whole-body concentrations exceeded 1 mg/kg. Smoltification and seawater migration have been shown to be impaired when whole-body concentrations of selenium were 2 - 3 mg/kg in juvenile chinook salmon (Lemly 1996); in habitats with low ambient selenium, concentrations usually range from 1 mg/kg to 5 mg/kg in tissue. Reduced growth, tissue damage in major organs, reproductive impairment, and mortality begin to occur at concentrations of 4 mg/kg to 16 mg/kg in tissue (Lemly 1996). The margin between normal concentrations and toxic concentrations in selenium is extremely narrow. This small margin of safety, when considered with the ability of selenium to bioaccumulate in aquatic food chains, highlights the importance of even slight increases in environmental selenium.

Based on the work on McKim et al. (1976), Wiener and Spry (1996) recommended that a concentration of 20 mg/kg be regarded as a no-observed-effect-concentration for mercury in salmonids, far greater than the concentrations in silver and chinook salmon fry in our study (0.1 mg/kg - 0.19 mg/kg).

<u>Slimy Sculpin</u>

There are few toxicity studies on slimy sculpin, so the toxicological significance of metal concentrations in this species is unknown, but slimy sculpin routinely have the greatest metals concentrations. All three slimy sculpin samples from this study were greater than the NCBP 85th percentile range for arsenic; concentrations were far greater than found in other species. Wagemann et al. (1978) reported that slimy sculpin readily accumulate arsenic. Slimy sculpin had greater mean concentrations than chinook and coho salmon of all elements measured except for copper. Concentrations of barium, cadmium, iron, manganese, lead, and strontium in whole body composite samples of slimy sculpin at Kanuti Refuge (Mueller et al. 1995) were far greater than concentrations of those elements in slimy sculpin at Illinois Creek. Slimy sculpin generally had greater values of aluminum, barium, chromium, and manganese than all other species collected at Kanuti, regardless of tissue type. Five of 10 slimy sculpin composite samples from Kanuti Refuge had cadmium concentrations greater than or equal to the NCBP 85th percentile of 0.44 mg/kg. The greatest cadmium concentration in slimy sculpin at Kanuti, 0.81 mg/kg, approached the NCBP maximum reported concentration of 0.88 mg/kg.

Tissue Differences

Tissues may have different metals concentrations depending upon the metal and routes of excretion or accumulation. Where significant differences in concentrations of metals occurred among tissues, the greater values were in kidney compared to muscle, except for magnesium in northern pike and Arctic grayling. Our results largely agree with those from Kanuti, Koyukuk, Northern Unit of Innoko, and Nowitna refuges (Table 30), and with those of Moore and Ramamoorthy (1984), who reported that cadmium accumulates primarily in major organ tissues rather than muscle. Jenkins (1980) reported the rank of copper concentrations in northern pike tissues from Ontario as liver> kidney> gill, and Miller et al. (1992) reported the rank of zinc in white sucker tissues as liver> ovary/bone/testis> gill> muscle. Bradley and Morris (1986) reported that liver was a good indicator of increased metal availability for copper, that kidney was best for nickel, and that muscle was a poor indicator.

Mercury behaves differently than other metals because bioavailable mercury is persistent and lipophilic. Although we found no significant differences among tissues, mercury concentrations were greater in muscle than in kidney at the Kanuti, Nowitna, and Selawik refuges (Snyder-Conn
Table 30. Significant differences ($P < 0.01$) of mean metal concentrations among northern pike

(*Esox lucius*) kidney (K), liver (L), and muscle (M) tissues from all sites at Koyukuk, Northern Unit of Innoko, Nowitna, and Kanuti National Wildlife Refuges, Alaska.

Refuge	Cd	Cu	Fe	Hg	Mg	Mn	Se	Zn
Kanuti[a]	K>L&M		K>L>M	M>L	M>K>L	K>M	L>M	K>L>M
Koyukuk[b]	K>L>M	L>K,M	K&L>M	K&M>L	M>K>L	L>M	K>L>M	K>L>M

[a] Mueller et al (1995).
[b] Mueller et al (1996).

et al. 1992b; Mueller et al. 1993; Mueller et al. 1995; Mueller et al. 1996), while Mueller et al. (1996) reported that mercury was greater in kidney and muscle of northern pike than in liver. Weiner and Spry (1996) observed that the concentrations of mercury in blood, spleen, kidney, liver, and brain decrease after exposure to mercury ceases and that muscle is the primary recipient of redistributed methylmercury. They also state that most methylmercury in the body eventually accumulates in muscle although concentrations are usually less than in other tissues. Allen-Gil et al. (1997) found that, with the exception of mercury, metal concentrations in muscle were lower than in liver for Arctic grayling and lake trout (*Salvelinus namaycush*). They noted that mercury was 90% methylmercury in muscle and 60% methylmercury in liver.
Detections of lead and strontium in whole body samples were likely due to the presence of skin and bone. Strontium concentrations in whole body samples were one to two orders of magnitude greater than in any other samples. Metals such as lead and strontium can accumulate in bone along with calcium (Newman 1998) and total concentrations, most of which is in bone, tend to increase with age (Goyer 1986; Eisler 1988a), although age is not a factor in this study. Competition of divalent cations, particularly calcium, appears to have an important influence on lead transfer, uptake, and retention in skin and skeleton of silver salmon (Pain 1995).

Inter-specific Differences

Whole-body slimy sculpin consistently had among the greatest concentrations of all metals (except mercury) compared to northern pike and Arctic grayling muscle samples; differences were sometimes an order of magnitude or more greater. Slimy sculpin in this study also had greater concentrations of arsenic, iron, manganese, selenium, and zinc than those reported by Jackson (1990) for northern pike on Innoko Refuge. At Kanuti Refuge in 1990, whole slimy sculpin had greater values of aluminum, barium, chromium, and manganese than all other species, regardless of tissue type, and in 1989, slimy sculpin had greater concentrations of aluminum, barium, copper, iron, manganese, and strontium than northern pike muscle (Mueller et al. 1995). As benthic feeders, slimy sculpin may ingest sediment along with their prey items and whole body analyses may therefore include analysis of sediment as well as tissue. This may have occurred for strontium and zinc, which in slimy sculpins were at or above sediment concentrations. However, mean sediment concentrations were greater for barium, boron, beryllium, copper, iron, manganese, nickel, lead, manganese, and vanadium compared to slimy sculpin. Whether the high metal values in slimy sculpin are due to diet, the presence of sediment in their gut, or other factors is unknown.

Many factors affect inter- and intraspecies-specific variation in accumulation and retention of mercury in fish (Sorensen 1991). In our study, diet may certainly be a factor. For biomagnifying contaminants such as mercury, higher trophic status generally leads to greater concentrations. Mercury concentrations in Interior Alaska were significantly greater in northern pike muscle than in Arctic grayling muscle (this study; Mueller et al. 1993; Mueller et al. 1995). At Kanuti Refuge, northern pike had the greatest mercury concentrations of all species, regardless of tissue type (Mueller et al. 1995).

Mean concentrations of boron in chinook salmon fry from California Creek were greater than in Arctic grayling or northern pike, in which it was generally not detected. The greatest value of boron in northern pike and Arctic grayling muscle and liver from Nowitna, Koyukuk, and Kanuti refuges was 3.03 mg/kg in a northern pike muscle sample (Snyder-Conn et al. 1992a,b; Mueller et al. 1995). Reasons for elevated boron levels in salmon fry are unknown.

The relationship of metals concentrations between Arctic grayling and northern pike muscle was more consistent than for kidney between years (Table 21). Northern pike had significantly greater concentrations of arsenic, magnesium, and mercury in muscle than Arctic grayling for both years. Arctic grayling had significantly greater concentrations of selenium in kidney and muscle than northern pike for both years. Significant differences between concentrations of copper and strontium did not occur.

Genetic Analysis of Chum Salmon and Coho Salmon

A complete report on genetic investigations on Innoko Refuge and the upper Little Mud River area are reported by Spearman et al. (2002).

For the process of natural selection to function as a part of evolution of a species, variability in the fitness of individuals must be genetic-based, i.e., some individuals must be more likely to survive and reproduce than others. If each individual were genetically identical, only chance would determine which individuals left progeny (Hunter 1995) and, as a result, populations would be less able to deal with environmental stress and more likely to be severely impacted should stressors occur. In the natural world, change is not the exception but the norm. Genetic diversity is an elemental quality of a biotic resource (Magnuson 1996).

Magnuson (1996) defines total genetic diversity in a species as: ...the sum of the variability over many hierarchical levels from the smallest local breeding population to the metapopulation to larger geographical areas that contain many metapopulations. Species with greater genetic diversity are more likely to adapt and evolve in response to a changing environment than those with less genetic diversity (Hunter 1995). Also, populations with low genetic diversity may have other problems such as low fertility and high mortality among offspring, even in unchanging environments (Hunter 1995). Due to the homing habit of salmon, the fundamental unit of replacement or recruitment is the local population (Ricker 1972), i.e., an adequate number of individuals for *each* local population is needed to ensure persistence of the many reproductive units that constitute a stock of salmon (Magnuson 1996). Local populations are adapted to the streams that support them. These adaptations are of great importance because they result in local populations being more able to survive and reproduce in their home stream than in other streams. Reestablishing lost populations has proven to be extremely difficult (Magnuson 1996).

Small populations are particularly susceptible to damage if a reduction of genetic diversity occurs. When a population collapse occurs in a small population, genetic diversity is likely to be reduced to only a sample of the original gene pool, and one not necessarily representative of the original (Hunter 1995). This is a genetic bottleneck. Small populations are also susceptible to random genetic drift which is the random change in gene frequencies occurring because each generation retains only a portion of the gene pool of the previous generation and, again, that sample may not be representative (Frankel and Soule 1981). Each of these phenomena restrict the adaptability of a species.

Chum Salmon

Neither mtDNA nor nuclear markers showed evidence of more than one population of chum salmon within each of the Innoko and Tanana river drainages. Spearman et al. (2002) concluded that relatively high gene flow among chum salmon occurred within each drainage and that chum salmon of the Innoko River may form a single population that is part of a larger complex of populations. No genetic evidence was found of multiple populations of chum salmon at California and Tolstoi creeks in the Innoko River drainage, however, this does not eliminate the possibility that multiple populations exist. Assuming that Innoko River chum salmon are a single population, damage to the Little Mud River drainage portion of that population would have less effect on chum salmon genetic diversity than if it was a unique population (Spearman et al. 2002). This conclusion does not reduce the value of this portion of the Innoko River population or of Illinois and California creeks as chum salmon habitat. Illinois and California creeks contain spawning and rearing habitat for chum salmon which, alone, has great value.

Coho Salmon

Coho salmon tend to form populations on a smaller geographic scale than chum salmon. Other investigators have reported genetic differentiation within and between drainages for coho salmon (Reisenbichler and Phelps 1987; Miller and Withler 1997). In our study, adult and juvenile coho salmon were collected for analysis. Collection of juvenile fish can potentially introduce biases through over-representation of family groups or collection of individuals from multiple populations due to migration of fish (Spearman et al. 2002). Collections of juvenile coho salmon for our study were not biased in either of these manners (Spearman et al. 2002) .

Multiple lines of evidence indicate that at least two populations of coho salmon exist within the Innoko River drainage, that there is restricted gene flow between at least two Innoko populations, and that no gene flow occurs between the Innoko and Tanana river populations (Spearman et al. 2002. The upper portion of the Little Mud River drainage, including Illinois and California creeks, likely has more than one population of coho salmon. As a result, damage to coho salmon runs in the Little Mud River drainage, by whatever means, has an increased likelihood of reducing the genetic diversity of coho salmon of that drainage. These populations of coho salmon are subject to the impacts of a genetic bottleneck which increases the probability of random genetic drift.

MAJOR FINDINGS

Water quality characteristics of rivers sampled during this study were circumneutral in pH, calcium- and magnesium-bicarbonate based, and typical of uncontaminated rivers. Rain caused an obvious difference in discharge and water quality in streams on the Refuge. Turbidity was significantly greater at sites sampled after a large rain event, and values for pH, conductivity, hardness and alkalinity were greater at sites sampled before the rain event. Water quality is not a consistent predictor of metals concentrations, as demonstrated by the changing relationships between metal concentrations and water quality variables associated with the rain event of 1996.

Surface waters in Innoko Refuge and the upper Little Mud River were relatively uncontaminated by metals. No samples exceeded the EPA chronic WQC for arsenic, however, total arsenic concentrations at several sites, including both sites on Illinois Creek, exceeded the drinking water standard for the State of Alaska. No dissolved metals concentrations exceeded the EPA WQC. Concentrations of total lead exceeded the EPA chronic WQC in two samples, however, it is unlikely that lead toxicosis is occurring at Innoko Refuge. Mean dissolved iron concentrations in all Innoko River drainage waters measured, except Tolstoi Creek, Illinois Creek, and California Creek, exceeded the EPA chronic WQC and the Canadian guideline for the protection of freshwater aquatic life.

Concentrations of metals in sediment at Innoko Refuge were within the range observed at other interior Alaska refuges except for arsenic, cadmium, iron, and manganese which were greater. The six sample sites in the upper Little Mud River drainage yielded four of the six greatest concentrations of arsenic and zinc in sediment in this study, and five of the six greatest lead concentrations in sediment. Sediment samples from Illinois Creek had the greatest concentrations of lead for all sites. Illinois Creek and the Little Mud River are mineralized drainages.

Concentrations of arsenic in one of 19 chinook salmon samples (California Creek) and all 5 silver salmon samples (Illinois Creek) were greater than the 85th percentile range of the National Contaminants Biomonitoring Program. Boron was detected in 17 of 19 chinook salmon fry in concentrations up to 10.0 mg/kg but not in silver salmon fry or Arctic grayling, and in only 5 northern pike muscle samples at the LOD of 1.0 mg/kg. We do not know if this is a result of differing conditions in the waterbodies or differing species. Salmonids are very sensitive to selenium contamination; chinook salmon fry from California Creek had up to 1.5 mg/kg and silver salmon from Illinois Creek had up to 1.3 mg/kg selenium.

All northern pike muscle samples but one from 1996 exceeded the greatest geometric mean of the NCBP for mercury and all but three exceeded the 85th percentile maximum value. Mercury concentrations in northern pike kidney were similar to those at Kanuti and Selawik refuges but less than those at the Nowitna Refuge.

There was no genetic evidence demonstrating multiple populations of chum salmon in California and Tolstoi creeks within the Innoko River drainage, although the possibility of the occurrence of such a difference has not been eliminated.

Coho salmon in the Innoko River drainage likely are comprised of more than one population. The upper Little Mud River drainage, including California and Illinois creeks, probably has more than one population of coho salmon.

RECOMMENDATIONS

Slimy sculpin consistently have high metals concentrations when compared to other species. Whether the high concentrations are due to diet, sediment in the gut, or other factors is unknown. A determination of the cause of high metals concentrations in slimy sculpin should be made.

Metals concentrations in water depend on many factors and foremost among these is the amount and pattern of recent precipitation in the drainage basin of concern. As a result, high variability among samples on both spatial and temporal levels can occur. Interannual variability in metals concentrations in sediments also occurs due to the heterogeneity of sediments, and the depositional and scouring patterns of streams. Although the data contained in this document can be used as baseline conditions, they should be used within the context of the inherent variabilities of aquatic systems. Periodic assessments of metals concentrations should be made, particularly if mining activities occur near the Refuge or if mining-related impacts to Refuge resources are suspected.

OTHER PUBLICATIONS RELATING TO INNOKO NATIONAL WILDLIFE REFUGE

Jackson, R. 1990. Report of findings: Innoko National Wildlife Refuge placer mining study. Ecological Services, U.S. Fish and Wildlife Service, Anchorage, AK. n.p.

Linne, M.J. 2000. Water resources inventory and assessment, Innoko National Wildlife Refuge. Water Resources Branch, U.S. Fish and Wildlife Service, Anchorage, AK. Progress Report WRB 00-01. 38 pp.

Major, E.B. 1997. Testing application of biological criteria in the mining environment. Environment and Natural Resources Institute, University of Alaska Anchorage for U.S. Environmental Protection Agency, Anchorage, AK. 29pp + appendices.

Millard, M.J. 1995. Preliminary assessment of the salmon stocks of the Innoko and Dishna Rivers, Innoko National Wildlife Refuge, Alaska, 1993. Fishery Resources Office - Fairbanks, AK, U.S. Fish and Wildlife Service, Fishery Data Series 95-2. 16pp.

Spearman, W.J., G.K. Sage, S.J. Miller, and B. Flannery. 2002. Genetic assessment of chum and coho salmon in the Innoko River drainage, Alaska, in an area adjacent to a mine. U.S. Fish and Wildlife Service, Conservation Genetics Laboratory, Anchorage. Alaska Fisheries Technical Report Series, In Press. 33 pp.

U.S. Fish and Wildlife Service. 1987. Innoko National Wildlife Refuge Comprehensive Conservation Plan, Environmental Impact Statement, and Wilderness Review. U.S. Fish and Wildlife Service, U.S. Department of Interior, Anchorage, AK. 255 pp.

LITERATURE CITED

Alaska Department of Environmental Conservation. 1991. 1990 Annual Mining Report, Juneau, AK. 39 pp.

Alaska Department of Natural Resources. 1986. Kuskokwim Area Plan, Minerals Element. Anchorage, AK. 40 pp.

Allen-Gil, S.M., C.P. Gubala, D.H. Landers, B.K. Lasorsa, E.A. Crecelius, and L.R. Curtis. 1997. Heavy metal accumulation in sediment and freshwater fish in U.S. Arctic lakes. Environ. Toxicol. and Chem. 16(4):733-741.

Alt, K. 1983. Inventory and cataloging of sport fish and sport fish waters of western Alaska. Federal Aid in Fish Restoration Research Project Completion Report, Vol. 24. Alaska Dept. Fish and Game, Juneau, AK.

Alt, K.T. 1985. Annual performance report for inventory and cataloging of sport fish and sport fish waters of western Alaska -- Nowitna and Fish-Niukluk Rivers, sheefish enhancement assessment. Pages 135-171 *in* Inventorying and Cataloging. Federal Aid in Fish Restoration and Anadromous Fish Studies. Vol. 26. Alaska Dept. Fish and Game, Juneau, AK.

Ambrose, R.E., A.C. Matz, T. Swem, and P. Bente. 2000. Environmental contaminants in American and arctic peregrine falcon eggs in Alaska, 1979-95. U.S. Fish and Wildlife Service Technical Report NAES-TR-00-01, Fairbanks, AK. 67 pp.

Atchinson, G.J., M.G. Henry, and M.B. Sandheinrich. 1987. Effects of metals on fish behavior: a review. Environ. Biology of Fishes 18(1):11-25.

Barrie, L.A., D. Gregor, B. Hargrave, R. Lake, D. Muir, R. Shearer, B. Tracey, and T. Bidleman. 1992. Arctic contaminants: sources, occurrence and pathways. Sci. Total Environ. 122:1-74.

Biesinger, K.E., and G.M. Christensen. 1972. Effects of various metals on survival, growth, reproduction, and metabolism of *Daphnia magna*. J. Fish. Res. Board Can. 29:1691-1700.

Bjerklie, D.M., and J.D. LaPerriere. 1985. Gold-mining effects on stream hydrology and water quality, Circle Quadrangle, Alaska. Water Resources Bull. 21:235-243.

Bradley, R.W., and J.R. Morris. 1986. Heavy metals in fish from a series of metal-contaminated lakes near Sudbury, Ontario. Water, Air, and Soil Poll. 27:341-354.

Buhl, K.J., and S.J. Hamilton. 1990. Comparative toxicity of inorganic contaminants released by placer mining to early life stages of salmonids. Ecotoxicol. and Environ. Safety 20:325-342.

Buhl, K.J., and S.J. Hamilton. 1991. Relative sensitivity of early life stages of Arctic grayling, coho salmon, and rainbow trout to nine inorganics. Ecotoxicol. and Environ. Safety 22:184-197.

Bundtzen, T.K., B.C. Cox, and N.C. Veach. 1987. Heavy mineral provenance studies in the Iditarod and Innoko Districts, western Alaska. Alaska Division of Geological and Geophysical Surveys, Public-data File 87-16. 25 pp.

Canadian Water Quality Guidelines. 1987. Canadian Water Quality Guidelines. Canadian Council of Resource and Environment Ministers. Ottawa, Ontario. v.p.

Clark, A.L., H.C. Berg, E.H. Cobb, G.D. Eberlein, E.M. Mackevett, Jr., and T.P. Miller. 1974. Metal provinces of Alaska. U.S. Geological Survey, Misc. Investig. Series Map I-834.

Clements, W.H., D.S. Cherry, and J. Cairns, Jr. 1988. Impact of heavy metals on insect communities in streams: A comparison of observational and experimental results. Can. J. Fish. Aq. Sci. 45:2017-2025.

Cobb, E.H. 1975a. Occurrences of chromite group metals in Alaska. U.S. Geological Survey, Mineral Investigation Resource Map MR-68 and Reference List. 2 pp.

Cobb, E.H. 1975b. Occurrences of platinum group metals in Alaska. U.S. Geological Survey, Mineral Investigation Resource Map MR-64 and Reference List. 2 pp.

Cobb, E.H. 1975c. Map showing occurrences of tungsten minerals in Alaska. U.S. Geological Survey, Mineral Investigation Resource Map MR-85 and Reference List. 6 pp.

Cobb, E.H. 1975d. Zinc occurrences in Alaska. U.S. Geological Survey, Mineral Investigation Resource Map MR-67 and Reference List. 9 pp.

Cobb, E.H. 1984a. Map showing occurrences of copper minerals in Alaska. U.S. Geological Survey, Mineral Investigations Resource Map MR-90 and Reference List. 19 pp.

Cobb, E.H. 1984b. Map showing occurrences of molybdenum minerals in Alaska. U.S. Geological Survey, Mineral Investigations Resource Map MR-86 and Reference List. 5 pp.

Cobb, E.H. 1984c. Map showing occurrences of lode gold and silver in Alaska. U.S. Geological Survey, Mineral Investigations Resource Map MR-84 and Reference List. 16 pp.

Cruz, E.L., and E.H. Cobb. 1984a. Map showing occurrences of mercury minerals in Alaska. U.S. Geological Survey, Mineral Investigations Resource Map MR-87 and Reference List. 4 pp.

Cruz, E.L., and E.H. Cobb. 1984b. Map showing occurrences of tin minerals in Alaska. U.S. Geological Survey, Mineral Investigation Resource Map MR-89 and Reference List. 4 pp.

Cruz, E.L., and E.H. Cobb. 1986. Map showing occurrences of antimony minerals in Alaska. U.S. Geological Survey, Mineral Investigations Resource Map MR-93 and Reference List. 5 pp.

Dietz, R., J. Pacyna, and D.J. Thomas. 1998. Heavy metals. Pages 373-524 *in* Arctic Monitoring and Assessment Programme Assessment Report: Arctic Pollution Issues. AMAP, Oslo, Norway. xii + 859 pp.

Eisler, R. 1978. Mercury contamination standards for marine environments. Pages 241-272 *in* J.H. Thorp and J.W. Gibbons, eds. Energy and environmental stress in aquatic systems. U.S. Dept. Energy Symp. Ser. 48, CONF-771114. Available from Natl. Tech. Infor. Serv., U.S. Dept. Commerce, Springfield, Virginia 22161.

Eisler, R. 1981. Trace metal concentrations in marine organisms. Pergamon Press, New York. 687 pp.

Eisler, R. 1985. Cadmium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.2). 46 pp.

Eisler, R. 1988a. Lead hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.14). 134 pp.

Eisler, R. 1988b. Arsenic hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.12). 92 pp.

Eisler, R. 1990. Boron hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.20). 32 pp.

Eisler, R. 1997. Zinc hazards to plants and animals with emphasis on fishery and wildlife resources. Pages 443-537 *in* P.N. Cheremisinoff, editor. Ecological issues and environmental impact assessment. Advances in Environmental Control Technology Series. Gulf Publishing Company, Houston, Texas.

Environment Canada. 1994. Cadmium and its compounds. Government of Canada, Environment Canada. Publication En 40-215/40E. 97 pp.

Ewald, G., P. Larsson, H. Linge, L. Okla, and N. Szarzi. 1998. Biotransport of organic pollutants to an inland Alaska lake by migrating sockeye salmon (*Oncorhynchus nerka*). Arctic 51(1):40-47.

Foley, J.Y., T. Hinderman, D. Kirby, and C. Mardock. 1984. Chromite occurrences in the Kaiyuh Hills, west-central Alaska.. C.C. Hawley and Associates, Incorporated, Anchorage, and Albany Research Center, Albany, Oregon for U.S. Department of the Interior, Bureau of Mines. Open File Report 178-84. 20 pp.

Ford, J., and T. Vlasova. 1996. Airborne contaminants in vegetation of arctic Alaska and

Russia. Pages 159-168 *in* R. Meehan, V. Sergienko, and G. Weller, eds. Bridges of science between North America and the Russian far east. Arctic Division, American Association for the Advancement of Science, Fairbanks, AK.

Forstner, U., and G.T.W. Wittmann. 1979. Metal pollution in the aquatic environment. Springer-Verlag, NY. 486 pp.

Frankel, O.H., and M.E. Soule. 1981. Conservation and Evolution. Cambridge University Press, Cambridge.

Giattina, J.D., R.R. Garton, and D.G. Stevens. 1982. Avoidance of copper and nickel by rainbow trout as monitored by a computer-based data acquisition system. Trans. Am. Fish. Soc. 111:491-504.

Gobeil, C., and D. Cossa. 1993. Mercury in sediments and sediment pore water in the Laurential Trough. Can. J. Fish. Aq. Sci. 50:1794-1800.

Goettl, J.P. Jr., and P.H. Davies. 1977. Water pollution studies. Colorado Department of Natural Resources, Division of Wildlife, Denver, CO. 68 pp.

Gower, A.M., G. Myers, M. Kent, and M.E. Foulkes. 1994. Relationships between macroinvertebrate communities and environmental variables in metal-contaminated streams in south-west England. Freshwater Biology 32:199-221.

Goyer, R.A. 1986. Toxic effects of metals. Pages 582 -635 *in* C.D. Klaassen, M.O. Amdur, and J.Doull, eds. Toxicology: the basic science of poisons. Macmillan Publishing Co., NewYork, NY. 974 pp.

Greenberg, A.E., L.S. Clesceri, and A. D. Eaton, eds. 1992. Standard methods for the examination of water and wastewater. 18th edition. American Public Healh Assosciation, American Water Works Association, and Water Environment Federation, Washington, DC. v.p.

Guthrie, R.K., E.M. Davis, D.S. Cherry, and H.E. Murray. 1979. Biomagnification of heavy metals by organisms in a marine microcosm. Bull. Environ. Contam. and Toxicol. 21:53-61.

Hach. 1992. Water Analysis Handbook. Hach Company, Loveland, CO. 831 pp.

Hamilton, S.J., and K.J. Buhl. 1990a. Acute toxicity of boron, molybdenum, and selenium to fry of chinook salmon and coho salmon. Arch. Environ. Contam. Toxicol. 19:366-373.

Hamilton, S.J., and K.J. Buhl. 1990b. Safety assessment of selected inorganic elements to fry of chinook salmon (*Oncorhynchus tshawytscha*). Ecotoxicol. and Environ. Safety 20:307-324.

Hamilton, S.J., and R.H. Wiedmeyer. 1990. Concentrations of boron, molybdenum, and selenium in chinook salmon. Trans. Am. Fish. Soc. 119:500-510.

Hansen, J., H.L. Bergman, J.S. Meyer, R. MacRae, J. Marr, J. Lipton, and D. Cacela. 1995. The avoidance of copper by salmonids as affected by metals concentration, organic content, and acclimation. Poster presented at the annual meeting of the Society of Environ. Toxicol. and Chem., Vancouver, B.C.

Headlee, P. 1996. Mercury and selenium concentrations in fish tissue and surface waters of the Northern Unit of the Innoko National Wildlife Refuge (Kaiyuh Flats), west central Alaska, 1993. Tanana Chiefs Conference, Inc., Fairbanks, Alaska. Water Resources Report No. 96-3.

Hem, J.D. 1992. Study and interpretation of the chemical characteristics of natural water. U.S. Geological Survey, Water-Supply Paper 2254. 264 pp.

Holzheimer, F.W. 1926. Galena Mine and Fourteen Prospect (Galena). Alaska Division of Geological and Geophysical Surveys, Prospects Examined Nulato SS-1. 4 pp. + photographs.

Hunn, J.B., S.J. Hamilton, and D.R. Buckler. 1987. Toxicity of sodium selenite to rainbow trout fry. Water Res. 21:233-238.

Hunter, M.L. Jr. 1995. Fundamentals of Conservation Biology. Blackwell Science, Cambridge, MA. 482 pp.

Jackson, R. 1990. Unpublished report of findings: Innoko National Wildlife Refuge placer mining study. Ecological Services, U.S. Fish and Wildlife Service, Anchorage, AK. n.p.

Jarvinen, A. W., and G.T. Ankley. 1999. Linkage of effects to tissue residues: development of a comprehensive database for aquatic organisms exposed to inorganic and organic chemicals. Soc. Environ. Toxicol. Chem., Pensacola, FL. 264 pp.

Jefferies, D., and J. Carey. 1994. Riverine inputs of contaminants, *in* J.L. Murray and R.G. Shearer, editors. Synopsis of research conducted under the 1993/1994 Northern Contaminants Program, Indian and Northern Affairs Canada. Ottawa, Canada.

Jenkins, D.W. 1980. Biological monitoring of toxic trace elements. Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency. EPA-600/3-80-090. Volumes 1 and 2.

Jensen, J., D. Adare, and R. Shearer, eds. 1997. Canadian Arctic Contaminants Assessment Report. Indian and Northern Affairs Canada. Ottawa, Canada. 460 pp.

Landers, D. H., J. Ford, C. Gubala, M. Monetti, B.K. Lasorsa, and J. Martinson. 1995. Mercury in vegetation and lake sediments from the U.S. Arctic. Water, Air, and Soil Pollution 80:591-601.

Lanno, R.P., and D. G. Dixon. 1994. Chronic toxicity of waterborne thiocyanate to the fathead minnow (*Pimephales promelas*): a partial life-cycle study. Environ. Toxicol.Chem. 13(9):1423-1432.

LaPerriere, J.D., S.M. Wagener, and D.M. Bjerklie. 1985. Gold-mining effects on heavy metals in streams, Circle quadrangle, Alaska. Water Res. Bull. 21(2):245-252.

Lemly, A. D. 1996. Selenium in aquatic organisms. Pages 427-445 *in* W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental Contaminants in Wildlife. Society of Environmental Toxicology and Chemistry, Lewis Publishers, New York.

Linne, M.J. 2000. Water resources inventory and assessment, Innoko National Wildlife Refuge. Water Resources Branch, U.S. Fish and Wildlife Service, Anchorage, AK. Progress Report WRB 00-01. 38 pp.

Lloyd, D.S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. N. Am. J. Fish. Manage. 7:34-45.

Lloyd, D.S., J.P. Koenings, and J.D. LaPerriere. 1987. Effects of turbidity in fresh waters of Alaska. N. Am. J. Fish. Manage. 7:18-33.

Lockhart, W.L., J.F. Uthe, A.R. Kenney, and P.M. Mehrle. 1972. Methylmercury in northern pike (*Esox lucius*): distribution, elimination, and some biochemical characteristics of contaminated fish. J. Fish. Res. Bd. Canada 29:1519-1523.

Lockhart, W.L., P. Wilkinson, B.N. Billeck, R.V. Hunt, R. Wagemann, and G.J. Brunskill. 1995. Current and historical inputs of mercury to high-latitude lakes in Canada and to Hudson Bay. Water, Air and Soil Pollution 80(1/4): 603-610.

Magnuson, J.J. 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington D.C. 452 pp.

Major, E.B. 1997. Testing application of biological criteria in the mining environment. Environment and Natural Resources Institute, University of Alaska Anchorage, for U.S. Environmental Protection Agency, Anchorage, Alaska. 29 pp. plus appendices.

Mannio, J. 1996. Data status: Finland. Finnish Environment Institute. From: Dietz, R., J. Pacyna, and D.J. Thomas. 1998. Heavy metals. Pages 373-524 *in* Arctic Monitoring and Assessment Programme Assessment Report: Arctic Pollution Issues. AMAP, Oslo, Norway. xii + 859 pp.

McElroy, D., P. Moran, E. Bermingham, and I. Kornfield. 1991. REAP: the restriction enzyme analysis package, version 4.0. Department of Zoology, Migratory Fish Research Institute and Center from Marine Studies, University of Maine, Orono, Maine 04469.

McKim, J.M., G.G. Olson, G.W. Holcombe, and E.P. Hunt. 1976. Long-term effects of methylmercuric chloride on three generations of brook trout (*Salvelinus fontinalis*): toxicity, accumulation, distribution, and elimination. J. Fish. Res. Board Can. 33:2726-2739.

Millard, M.J. 1995. Preliminary assessment of the salmon stocks of the Innoko and Dishna Rivers, Innoko National Wildlife Refuge, Alaska, 1993. Fishery Resources Office - Fairbanks, AK, U.S. Fish and Wildlife Service, Fishery Data Series 95-2. 16pp.

Miller, KM., R.E. Withler, T.D. Beacham. 1996. Stock identification of coho salmon (*Oncorhynchus kisutch*) using minisatellite DNA variation. Can. J. Fish. Aquat. Sci. 53:181-195.

Miller, P.A., K.R. Munkittrick, and D.G. Dixon. 1992. Relationship between concentrations of copper and zinc in water, sediment, benthic invertebrates, and tissues of white sucker (*Catostomus commersoni*) at metal-contaminated sites. Can. J. Fish. Aquat. Sci. 49:978-984.

Moore, J.W., and S. Ramamoorthy. 1984. Heavy metals in natural waters: applied monitoring and impact assessment. Springer-Verlag, N.Y. 268 pp.

Morrow, J.E. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing Co., Anchorage, AK. 248 pp.

Morsell, J.W. 1991. Aquatic resources assessment study, Illinois Creek gold project. Prepared for North Pacific Mining Corporation, Anchorage, Alaska, by Northern Ecological Services, Anchorage, Alaska. 9 pp.

Mueller, K.A., E. Snyder-Conn, and M. Bertram. 1996. Water quality and metal and metalloid contaminants in sediments and fish of Koyukuk, Nowitna, and the Northern Unit of Innoko National Wildlife Refuges, Alaska, 1991. Ecological Services Fairbanks, AK, U.S. Fish and Wildlife Service, Technical Report NAES-TR-96-03. 68 pp. + appendices.

Mueller, K.A., E. Snyder-Conn, and T. Doyle. 1993. Contaminant baseline data for water, sediments, and fish of Selawik National Wildlife Refuge, Alaska, 1987-1988. Ecological Services, Fairbanks, AK, U.S. Fish and Wildlife Service, Technical Report NAES-TR-93-02. 84 pp. + appendices.

Mueller, K.A., E. Snyder-Conn, and P.O. Scannell. 1995. Metal and metalloid contaminants in water, sediments, fish, and mammals of Kanuti National Wildlife Refuge, Alaska, 1985-1990. Ecological Services Fairbanks, AK, U.S. Fish and Wildlife Service, Technical Report NAES-TR-95-02. 125 pp. + appendices.

Muir, D, and 23 authors. 1997. Ecosystem uptake and effects. Pages 191-294 *in* J. Jensen, K Adare, and R. Shearer, eds. Canadian Arctic Contaminants Assessment Report, Indian and Northern Affairs Canada, Ottawa. pp.

Neter, J., M.H. Kutner, C.J. Nachtsheim, and W. Wassermen. 1996. Applied Linear Statistical Models, 4th Edition. Irwin Publishing, Chicago, IL. 1408 pp.

Newman, M.C. 1998. Fundamentals of Ecotoxicology. Ann Arbor Press, MI. 402 pp.

Nokleberg, W.J., T.K. Bundtzen, H.C. Berg, D.A. Brew, D. Grybeck, M.S. Robinson, T.E. Smith, and W. Yeend. 1987. Significant metalliferous lode deposits and placer districts of Alaska. U.S. Geological Survey Bulletin 1786. 104 pp. + 2 maps.

Outridge, P.M., D.D. MacDonald, E. Porter, and I.D. Cuthbert. 1994. An evaluation of the ecological hazards associated with cadmium in the Canadian environment. Environ. Rev. 2:91-107.

Pain, D.J. 1995. Lead in the environment. Pages 356-391 *in* D.J. Hoffman, B.A. Rattner, G.A.Burton, Jr. and J Cairns, Jr., eds. Handbook of Ecotoxicology. Lewis Publishers, Boca Raton, FL. 755 pp.

Persuad, D., R. Jaagumagi, and A. Hayton. 1992. Guidelines for the protection and management of aquatic sediment quality in Ontario. Water Resources Branch, Ontario Ministry of the Environment. 26 pp.

Rainbow, P.S. 1996. Heavy metals in aquatic invertebrates. Pages 405-425 *in* W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental Contaminants in Wildlife. Society of Environmental Toxicology and Chemistry, Lewis Publishers, New York.

Rand, G.M., P.G. Wells, and L.S. McCarty. 1995. Introduction to aquatic toxicology, Pages 3-67 *in* G.M. Rand, ed. Fundamentals of Aquatic Toxicology. Taylor and Francis, Washington D.C. 1125 pp.

Reiger, S., D. Schoephorster, and C.E. Furbush. 1979. Exploratory soil survey of Alaska. U.S. Dept. Agriculture, Soil Conservation Service. 213 pp. plus maps.

Reisenbichler, R.R., and S.R. Phelps. 1987. Genetic variation in chinook, *Oncorhynchus tshawytscha*, and coho, *O. kisutch*, salmon from the north coast of Washington. Fish. Bull. 85:681-701.

Rice, W.R. 1989. Analyzing tables of statistical tests. Evolution 43:223-225.

Ricker, W.E. 1972. Hereditary and environmental factors affecting certain salmonid populations. Pages 19-160 *in* R.C. Simon and P.A. Larkin, eds. The Stock Concept in Pacific Salmon. University of British Columbia, Vancouver.

Roff, D.A. and P. Bentzen. 1989. The statistical analysis of mitochondrial DNA polymorphisms: ^{2} and the problem of small samples. Molecular Biology and Evolution 6:539-

545.

Saiki, M.K, M.R. Jennings, and R.H. Wiedmeyer. 1992. Toxicity of agricultural subsurface drainwater from the San Joaquin Valley, California, to juvenile chinook salmon and striped bass. Trans. Am. Fish. Soc. 121:78-93.

Saiki, M.K., M.R. Jennings, and R.H. Wiedmeyer. 1993. Boron, molybdenum, and selenium in aquatic food chains from the lower San Joaquin River and its tributaries, California. Arch. Environ. Contam. Toxicol. 24:307-319.

Sandheinrich, M.B. and G.J. Atchison. 1989. Sublethal copper effects on bluegill, *Lepomis macrochirus*, foraging behavior. Can. J. Fish. Aquat. Sci. 46:1977-1985.

Schmitt, C.J., J.L. Zajicek, T.W. May, and D.F. Cowman. 1999. Organochlorine residues and elemental contaminants in U.S. freshwater fish, 1976-1986: National Contaminant Biomonitoring Program. Rev. Environ. Contam. Toxicol. 162:43-104.

Schindler, D.W., K.A. Kidd, D.C.G. Muir, and W.L. Lockhart. 1995. The effects of ecosystem characteristics on contaminant distribution in northern freshwater lakes. Sci. Total Environ. 160/161:1-17.

Scribner, K.T., P.A. Crane, W.J. Spearman, and L.W. Seeb. 1998. DNA and allozyme markers provide concordant estimates of population differentiation: analyses of U.S. and Canadian populations of Yukon River fall-run chum salmon (*Oncorhynchus keta*). Canadian Journal of Fisheries and Aquatic Science 55:1748-1758.

Skotvold, T., E.M.M. Wartena, and S. Rognerud. 1996. Heavy metals and persistent organic pollutants in sediments and fish from lakes on northern and arctic regions of Norway. Akvaplan-nina, Tromso. 77 pp.

Snyder-Conn, E., M. Bertram, and P. Scannell. 1992a. Contaminant data for water, sediments, and fish of the Koyukuk National Wildlife Refuge and the Northern Unit of Innoko National Wildlife Refuge. Ecological Services, Fairbanks, AK, U.S. Fish and Wildlife Service, Technical Report NAES-TR-92-04. 78 pp. + appendices.

Snyder-Conn, E., T. Patton, M. Bertram, P. Scannell, and C. Anthony. 1992b. Contaminant baseline data for water, sediments, and fish of the Nowitna National Wildlife Refuge, 1985 - 1988. Ecological Services, Fairbanks, AK, U.S. Fish and Wildlife Service, Technical Report NAES-TR-92-02. 69 pp. + appendices.

Sorenson, E.M. 1991. Metal poisoning in fish. CRC Press, Boston, MA. 374 pp.

Spearman, W.J., G.K. Sage, S.J. Miller, and B. Flannery. 2002. Genetic assessment of chum and coho salmon in the Innoko River drainage, Alaska, in an area adjacent to a mine. U.S. Fish and Wildlife Service, Conservation Genetics Laboratory, Anchorage. Alaska Fisheries Technical Report Series, In Press. 33 pp.

Sprague, R.W. 1972. The ecological significance of boron. U.S. Borax Research Corp., Anaheim, CA. 58 pp.

SRK. 1995. Illinois Creek project, ore and waste rock characterization. Steffen, Robertson, and Kirsten, Lakewood, CO. Prepared for USMX Inc., Lakewood, CO. Project No. 51407. 4 pp plus attachments.

Swainbank, R.C., T.K. Bundtzen, A.H. Clough, M.W. Henning, and E.W. Hansen. 1995. Alaska s mineral industry 1994. State of Alaska, Department of Natural Resources, Division of Geological and Geophysical Surveys, Special Report 49. 77 pp.

Swainbank, R.C., and K.H. Clautice. 1998. Alaska s mineral industry 1997. State of Alaska, Department of Natural Resources, Division of Geological and Geophysical Surveys, Information Circular 43. 12 pp.

Sykora, J.L., E.J. Smith, M.A. Shapiro, and N. Synkak. 1972. Chronic effect of ferric hydroxide on certain species of aquatic animals. Proc. Symp. on Coal Mine Drainage Research 4:347-369. Mellon Institute, Pittsburgh, PA.

Taube, T. 1995. Memorandum to P. Merritt, Alaska Department of Fish and Game, Sport Fish Division. 25 pp.

Thompson, J.A.J., J.C. Davis, and R.E. Drew. 1976. Toxicity, uptake and survey studies of boron in the marine environment. Water Res. 10:869-875.

Timmermans, K.R. 1993. Accumulation and effects of trace metals in freshwater invertebrates. Pages 134-148 *in* R. Dallinger, and P.S. Rainbow, eds. Ecotoxicology of Metals in Invertebrates. Lewis Publishers, Boca Raton, FL.

U.S. Environmental Protection Agency. 1986. Quality Criteria for Water 1986. Office of Water Regulations and Standards, U.S. EPA, Washington D.C. EPA 440/5-86-001. v.p.

U.S. Environmental Protection Agency. 1992. National study of chemical residues in fish. Office of Science and Technology, U.S. Environmental Protection Agency, Washington D.C. EPA 823-R-92-008a. v.p.

U.S. Environmental Protection Agency. 1999. National Recommended Water Quality Criteria. U.S. EPA, Office of Water, Washington D.C. EPA 882-Z-99-001. 25 pp.

U.S. Fish and Wildlife Service. 1987. Innoko National Wildlife Refuge Comprehensive Conservation Plan, Environmental Impact Statement, and Wilderness Review. U.S. Fish and

Wildlife Service, U.S. Department of Interior, Anchorage, AK. 255 pp.

U.S.M.X. 1995. Illinois Creek gold mine project profile - Alaska. U.S.M.X. Inc., February 1995, Lakewood, CO. v.p.

Van Nieuwenhuyse, E.E., and J.D. LaPerriere. 1986. Effects of placer gold mining on primary production in subarctic streams of Alaska. Water Resources Bull. 22:91-99.

Wagemann, R., N.B. Snow, D.M. Rosenberg, and A. Lutz. 1978. Arsenic in sediments, water and aquatic biota from lakes in the vicinity of Yellowknife, Northwest Territories, Canada. Arch. Environ. Contam. Toxicol. 7:169-191.

Wagener, S.M., and J.K. LaPerriere. 1985. Effects of placer mining on the invertebrate communities of interior Alaska streams. Freshwater Invert. Biol. 4:208-214.

Weber, P., and R. Post. 1985. Aquatic habitat assessment in mined and unmined portions of the Birch Creek watershed. Alaska Dept. Fish and Game, Habitat Division, Report 85-2, Juneau, AK. 65 pp.

Weber Scannell, P. 1993. Effects of increased sedimentation on freshwaters of interior Alaska. Proc. Tech. Workshop on Sediments. U.S. Environmental Protection Agency and U.S. Forest Service, Corvallis, OR. February 3-7, 1992. 15 pp. Terrene Institute, Washington D.C.

West, R.L., and N.A. Deschu. 1984. Kantishna Hills heavy metals investigations, Denali National Park, 1983. National Park Service, Anchorage, AK. 42 pp.

West, R.L., M.W. Smith, W.E. Barber, J.B. Reynolds, and H. Hop. 1992. Autumn migration and overwintering of Arctic grayling in coastal streams of Arctic National Wildlife Refuge, Alaska. Trans. Am. Fish. Soc. 121:709-715.

Wiener, J.G., and D.J. Spry. 1996. Toxicological significance of mercury in freshwater fish. Pages 297-339 *in* W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental Contaminants in Wildlife. Society of Environmental Toxicology and Chemistry, Lewis Publishers, New York.

Winters, J. F. 1996. Illinois Creek mine fish monitoring study: Emphasis on juvenile coho salmon. Alaska Dept. Fish and Game, Habitat Division, Technical Report 96-7, Juneau, AK. 44 pp.

Winters, J. F. 1997. Illinois Creek mine fish monitoring study: Emphasis on juvenile coho salmon - Year 2 (1996). Alaska Dept. Fish and Game, Habitat Division, Juneau, AK. 8 pp.

Winters, J. F. 1998a. Illinois Creek mine fish monitoring study: Emphasis on juvenile coho salmon - Year 3 (1997). Alaska Dept. Fish and Game, Habitat Division, Juneau, AK. 7 pp.

Winters, J. F. 1998b. Illinois Creek mine fish monitoring study: Emphasis on juvenile coho salmon - Year 4 (1998). Alaska Dept. Fish and Game, Habitat Division, Juneau, AK. 6 pp.

Wright, S. 1965. The interpretation of population structure by F-statistics with special regard to systems of mating. Evolution 19:395-420.

APPENDIX A: DOCUMENTATION AND SAMPLE HANDLING

STUDY PROPOSALS

A study proposal was submitted prior to each year of sampling. Study plans included objectives of the study, a discussion of the justification for the study including a review of related research, a methods section including discussion of collection and analysis procedures, topographic maps indicating anticipated sample locations, and a cost proposal based on number and types of samples to be collected.

FIELD DOCUMENTATION

During field studies, sample documentation was recorded in a waterproof field notebook in permanent ink. The date and time of collections at each site were specified as were the results of all water quality analyses. The latitude and longitude of the sample site location was determined using the Geographic Positioning System in the helicopter. Sample identifications were listed by sample type for each sample collected. Data on fish species, including the whole weight, fork length, and total length were also listed in the field notebook.

SAMPLE CATALOG

A sample catalog was prepared for each year's samples by matrix. The catalog contained study objectives; background information (including number of water quality, sediment, and tissue samples); previous findings and concerns; possible interfering elements in the analyses; methods of preservation and storage; instructions to the laboratory, including a description of the analyses requested together with the suggested analytical method; a list of data recipients; a cost estimate for the requested analyses; and a tabulated summary of information on each sample. This information included the sample identification, the date of collection, the type of sample or tissue, the species (for fish samples), the sample location, sample weight or volume, and analyses requested for each particular sample. The catalogs were submitted to the following analytical laboratories:

Catalog	Regional I.D.	Matrix	Laboratory Address
7030046	7N14	Water	Research Triangle Institute (RTI) 3040 Cornwallis Road P.O. Box 12194 Research Triangle Park, NC 27709-2194
7030047	7N14	Sediment	Research Triangle Institute
7030048	7N14	Tissue	Environmental Trace Substances Laboratory University of Missouri-Rolla 101 USBM Building 1300 North Bishop Avenue Rolla, MO 65409-0530
7030053	7N14	Water	Environmental Trace Substances Laboratory
7030054	7N14	Sediment	Texas A&M Research Foundation Trace Element Research Laboratory 100 Bizzell Street Eller Building, Room 403 College Station, TX 77843-3146
7030057	7N14	Tissue	Environmental Trace Substances Laboratory

Catalogs were inspected by a Quality Assurance Officer at the Patuxent Analytical Control Facility. Upon approval, they were forwarded to the laboratory together with the listed samples. Laboratory data were received by the authors following review and approval by the Quality Assurance Officer.

CHAIN OF CUSTODY

No chain of custody forms accompanied these catalogs. Sampling was performed for baseline information, and was not anticipated to be used in legal proceedings.

SAMPLE STORAGE AND SHIPMENT

In the field, all samples were placed in coolers with blue ice and transported to a refrigerator (water) or a freezer (sediment and fish tissue) for storage. Samples were shipped to Fairbanks where they were held in a refrigerator (water) or an ultralow freezer at minus 40°C (sediment and fish tissue) until shipment to the analytical laboratory. Frozen samples were shipped with dry ice and blue ice to the analytical laboratory.

SAMPLE HOLDING TIMES

No holding times have been established for metals in sediments or tissues; however, it is widely assumed that loss from these media by volatilization or plating onto the container wall would be minimal. No sample holding times were exceeded.

APPENDIX B: QUALITY ASSURANCE/QUALITY CONTROL OF CHEMICAL ANALYSES

The U.S. Fish and Wildlife Service maintains contracts with several analytical laboratories, and also performs analytical work at the Patuxent Analytical Control Facility, Patuxent National Wildlife Research Center (PACF), Laurel, Maryland, to determine the inorganic and organic composition of samples.

Contract laboratories are selected by a PACF technical committee using a process involving the correct analysis of samples submitted to prospective laboratories by PACF, and a review of the laboratory, its procedures, facilities, experience, personnel, and cost structure. A final step in selecting a laboratory is an on-site inspection by representatives of the evaluation committee. Continued round-robin testing and cross-checking of contract laboratories by PACF has been used to monitor their performance and alert the Service's Quality Assurance Project Officer of systematic analytical problems with particular analytes. Approximately 5% of all sample catalogs submitted for analysis to contract laboratories are also reanalyzed by PACF. In addition to these QA-QC measures, precision, accuracy, and potential laboratory contamination of samples are evaluated through the analysis of specific quality control samples. Reports produced by contract laboratories are required to contain the following:

1. A brief description of the methods used in the analysis.
2. The analytical results.
3. Results of any QA-QC samples analyzed in conjunction with the reported catalog, including:
    a. Limits of detection for each sample
    b. Duplicate analysis
    c. Spiked sample analysis
    d. Standard reference material (SRM) analysis
    e. Procedural blank analysis
4. A description of any problems encountered in the analysis.

The laboratory may also be required to submit copies of all raw data collected during the analysis upon request. The laboratories provide a description of their analytical methods and specific instrumentation used, including model numbers.

QA-QC data produced during this study were evaluated by analyte using the following parameters:

Duplicate Analysis RPDs	Mean of 20%
Spike Percent Recoveries	Mean of 20% using the absolute value of the difference from100% recovery to account for imprecisions of greater than or less than 100% recovery.
Standard Reference Materials	20% using the absolute value difference from 100% recovery as above.

LIMITS OF DETECTION

The criterion "limit of detection" (LOD) has been variously defined and its determination is the subject of controversy (Greenberg et al. 1992). A general definition for LOD is that it is the lowest concentration level that can be distinguished statistically from a blank sample. That is, it is a reliable limit for an analyte, above which values are consistently detectable and distinguishable from instrument noise. Samples reported as being below the detection limit in a data set are reported as <X where X is the LOD.

Individual sample LOD's may also be reported by the laboratory. These are generally shown adjacent to the measured concentration of an analyte in the sample. Because the method LOD varies depending on the nature of the individual sample, the upper LOD reported for each matrix in a sample catalog was adopted as the LOD for QA-QC screening of the data.

ANALYTICAL PRECISION

Precision refers to the degree of agreement among repeated measurements of a given sample. Precision varies with such factors as the homogeneity of the sample, sample volume, sample matrix, instrumental method, instrumental drift, chemical interferences, and the analyte concentration in the sample relative to the LOD. Estimates of precision used for this study were made using duplicate analysis, where at least two subsamples of a homogenized sample are collected and analyzed by the laboratory. Precision is monitored by the laboratory using range ratio control charts for each analyte of each matrix (e.g., sediment, tissue). The measure selected for estimating precision by the QA-QC analysis program is the relative percent difference (RPD):

$$RPD = ([D_1 - D_2]/[(D_1 + D_2)/2]) \times 100$$

where RPD is the relative percent difference, D_1 is the concentration as determined by the first analysis, and D_2 is the concentration as determined by the second analysis.

Acceptable precision is based not only on the absolute value of the RPD, but also on the relationship between the concentration of the analyte and the LOD for that analyte. For duplicate samples with analyte concentrations where both values are less than the LOD, no estimate of precision is made because this comparison is normally inappropriate (Greenberg et al. 1992). For sample concentrations less than twice the LOD, precision is expected to be low, because instrument performance typically declines as the LOD is approached. The 95% confidence interval for these cases is assumed to be 2(LOD). Samples with concentrations less than 2(LOD) are not rejected based on poor precision but are considered qualitative analyses.

Average RPD's for each analyte and each matrix are calculated separately. For concentrations of an analyte >2(LOD) and <10(LOD), results are expected to be semi-quantitative, and dependent on their relation to the LOD. In these samples, both precision and accuracy may be reduced. For measurements >10(LOD), analyses are expected to be highly quantitative.

ANALYTICAL ACCURACY

Spiked Samples

In addition to precision, measurements of correctness of the analyses are needed to guarantee the quality of semi-quantitative (>2<10 LOD) and quantitative (>10 LOD) data, and to estimate chemical interferences that may occur. One method used by our contract laboratories to estimate accuracy and gauge interference is spiked samples. This method consists of dividing a homogenized sample into two subsamples, analyzing one as the sample, spiking the other subsample with a known quantity of one or more analytes, and analyzing the resulting mixture. The difference between the two subsamples, after accounting for any differences in sample weight, is the spike recovery. This value is usually reported as a percentage of the amount added.

Another reason for imprecise metal recoveries is incomplete digestion of the sample material. Unless specified in the catalog instructions, metal digestions performed on sediment samples by contract laboratories are incomplete, resulting in the release of some, but not all, of the analyte. Such digestions give what are referred to as "total recoverable metals" or "acid-soluble metals." Metals recovered are those that would be readily available for uptake in an acidic environment. Theoretically, these are the metals concentrations of biological significance, in terms of availability for rapid biogeochemical cycling. Metals that remain bound in the matrix are more tightly bound, either by chemical complexing or by physical processes, and may not become biologically available under any natural circumstance. Typically, those analytes bound as silicates are not recovered. Occasionally, total digestion (using hydrofluoric acid rather than nitric and perchloric acid) is performed when spike recoveries are not satisfactory during the partial digestion. Usually, the amount of spiking solution added to a sample is sufficient to result in a concentration of that analyte of more than twice the original concentration in the sample and >2(LOD).

In general, Service contract laboratories perform incomplete digestions with nitric and perchloric acids; our interests center on the metals that are biologically available. The result is often nearly complete recovery of trace metals, such as cadmium, and poorer recovery of common metals, such as aluminum, iron, and manganese, which tend to form numerous tightly bound metallic complexes.

Standard Reference Materials

Standard reference materials (SRM's) provided by an outside agency or commercial source represent an additional means of gauging the accuracy of analytical results. Usually the SRM analyzed concurrently with the samples is of the same matrix. SRM's typically contain natural or slightly elevated levels of each analyte in a diversity of valence states, compounds, and complexes that may naturally be present in water, sediments, and tissues. Therefore, high accuracy in performing SRM analysis is frequently more difficult than accuracy in performing spike analysis.

Sources of SRM's included the National Institute of Standards and Technology (formerly the National Bureau of Standards), and the National Research Council of Canada (NRCC). Certified values provided by the source are usually determined by repeated analysis of the analyte using several different methods (e.g., atomic absorption spectrometry, X-ray fluorescence, and inductively coupled plasma spectrometry). The certified value for each analyte, or "true value," is typically the weighted mean of the different methods. A standard deviation is also calculated and used to provide a certified range. The method for creating this range varies somewhat depending on the source of the analyte. In some cases, a considerable amount of professional judgement is used to define this range.

Because the total recoverable metals method of digestion, as described above, is used for sediment samples by the Fish and Wildlife Service and a total metals digestion method is used by producers of SRMs, the apparent recovery for sediment samples by Fish and Wildlife Service contract laboratories is consistently low for some analytes. As a result, acceptance of laboratory analyses for SRMs is based on the expected recoveries as determined by past contract laboratory performances not simply the recovery as for water and tissue samples.

Blanks

Blanks are samples expected to have negligible or undetected concentrations of the analytes of interest. Blanks may be used to evaluate the presence of contaminants as a result of either field or laboratory procedures. Blanks generally consist of distilled and/or deionized water, although some laboratories may utilize other matrices. Field (or transport) blanks may be used to estimate incidental contamination in the field and during storage and shipment. Field blanks are created by taking capped and clean containers filled with distilled water into the field and uncapping them for the required sample period. They are treated like other field samples in regards to preservation, chilling or freezing, handling, and labeling. They are stored, shipped, and analyzed with the other samples.

Several types of blanks may be employed by the analytical laboratory to estimate external and internal contamination. These include a sample preparation blank, matrix blank, and reagent blank. The sample preparation blank is used to detect contamination when stirring, blending or subsampling occurs. This type blank can therefore be used to evaluate whether the equipment cleaning procedures are adequate. Matrix blanks are sometimes also used for sediment and tissue samples, and when a reagent blank analysis indicates contamination. A reagent blank is distilled and deionized water that is passed through the analytical procedure with the other samples. Reagent blanks are subjected to the same digestion procedures as samples. If contaminants are detected at levels that may compromise the results of the analysis and are not systematic, the above breakdown is needed to identify sources of contamination.

The laboratory may run a single blank through the entire analytical process, including sample preparation and reagent treatment. If contaminants detected during the entire process are negligible, then separate sample preparation and reagent blanks are not necessary. Also, if blank contaminant levels are recurring (i.e., nonrandom), the blank values may be subtracted from the data set.

The maximum reagent blank concentration of an analyte is considered the blank for analysis of QA/QC data. If the maximum reagent blank concentration exceeds the LOD, ten times the maximum blank is used at the qualitative/quantitative cutoff.

Literature Cited:

Greenberg, A.E., L.S. Clesceri, and A.D. Eaton. 1992. Standard Methods for the Examination of Water and Wastewater. 18th Edition. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Washington D.C. v.p.

APPENDIX C: QUALITY ASSURANCE/QUALITY CONTROL SCREENING RESULTS

Catalog 7030046
Innoko NWR - Water 1996

Element	LOD[1] (mg/L)	Duplicate Analyses (Mean RPD[2])	Mean Spike Recovery[3] (%)	Mean SRM[4] Recovery (%)	Maximum Blank	Blank-Based Precision Cutoff[5] (mg/L)
Al	0.0222	10	98	-	<LOD	0.222
As	0.0056	0	97	-	<LOD	0.056
B	0.0111	Qualitative	96	-	<LOD	0.111
Ba	0.0011	4	98	-	<LOD	0.011
Be	0.0006	Qualitative	98	-	<LOD	0.006
Cd	0.0006	Qualitative	95	-	<LOD	0.006
Cr	0.0056	12	97	-	<LOD	0.056
Cu	0.0056	7	98	-	<LOD	0.056
Fe	0.0222	7	96	-	<LOD	0.222
Pb	0.0111	Qualitative	95	-	<LOD	0.111
Mg	0.0222	6	93	-	<LOD	0.222
Mn	0.0022	5	97	-	<LOD	0.022
Mo	0.0044	Qualitative	96	-	<LOD	0.044
Hg	0.0003	Qualitative	96	95	<LOD	0.003
Ni	0.0056	16	96	-	<LOD	0.056
Se	0.0056	Qualitative	97	-	<LOD	0.056
Sr	0.0022	4	98	-	<LOD	0.022
V	0.0044	12	97	-	<LOD	0.044
Zn	0.0111	12	96	-	<LOD	0.111

[1] - Limit of Detection.
[2] - Relative Percent Difference. RPDs <20 are acceptable. N = up to seven.
[3] - Spike recoveries 80% are acceptable. N = 14.
[4] - Standard Reference Material. The percent deviation of an SRM analysis result from the certified mean value. No values are reported (except for mercury) because the laboratory used extra spikes instead of SRMs.
[5] - Sample results greater than the listed figure are considered quantitative data. Values less than the listed figure are considered semi-quantitative or qualitative depending on their relation to the LOD.

Mercury in Water for 1996
Analyses conducted by Frontier Geosciences

Element	LOD[1] (ng/L)	Duplicate Analyses (Mean RPD[2])	Mean Spike Recovery[3] (%)	Mean SRM[4] Recovery (%)	Maximum Blank	Blank-Based Precision Cutoff[5] (ng/L)
Hg	0.12	7	90	98	<LOD	1.2

[1] - Limit of Detection.
[2] - Relative Percent Difference. RPDs <20 are acceptable. N = up to four.
[3] - Spike recoveries 80% are acceptable. N = up to four.
[4] - Standard Reference Material. The percent deviation of an SRM analysis result from the certified mean value. Mean SRM values 80% are acceptable. N = up to four.
[5] - Values greater than the listed figure are considered quantitative data. Values less than the listed figure are considered semi-quantitative or qualitative depending on their relation to the LOD.

Catalog 7030047
Innoko NWR - Sediment 1996

Element	LOD[1] (mg/L)	Duplicate Analyses (Mean RPD[2])	Mean Spike Recovery[3] (%)	Mean SRM[4] Recovery (%)	Maximum Blank	Blank-Based Precision Cutoff[5] (mg/L)
Al	103	7	S/B<1[6]	21	<LOD	1030
As	0.53	5	96.39	74	<LOD	5.3
B	5.19	6	86.89	NCV[7]	<LOD	51.9
Ba	3.09	5	81	19	<LOD	30.9
Be	0.21	Qualitative[8]	98	NCV	<LOD	2.1
Cd	0.21	7	98	88	<LOD	2.1
Cr	5.13	7	97	58	<LOD	51.3
Cu	5.23	3	96	86	<LOD	52.3
Fe	106	3	S/B<1	67	<LOD	1060
Hg	0.1059	Qualitative	97	94	<LOD	1
Mg	106	5	S/B<1	87	<LOD	1060
Mn	4.24	3	S/B<1	81	<LOD	42.4
Mo	5.31	Qualitative	97	NCV	<LOD	53.1
Ni	5.19	5	98	84	<LOD	51.9
Pb	5.3	3	97	94	<LOD	53
Se	0.53	Qualitative	78	90	<LOD	5.3
Sr	2.12	6	95	Fail	<LOD	21.2
V	5.3	5	98	20	<LOD	53
Zn	5.3	5	96	89	<LOD	53

[1] - Limit of Detection.
[2] - Relative Percent Difference. RPDs <20 are acceptable. N = up to four.
[3] - Spike recoveries 80% are acceptable. N = up to four.
[4] - Standard Reference Material. The percent deviation of an SRM analysis result from the certified mean value. Acceptable Mean SRM values are based on past laboratory performance. N = up to four. See text for further explanation.
[5] - Values greater than the listed figure are considered quantitative data. Values less than the listed figure are considered semi-quantitative or qualitative depending on their relation to the LOD.
[6] - Spike/Background ratio <1, therefore, these values were not used.
[7] - No Certified Value for this analyte.
[8] - At least one duplicate analysis of each pair was in the qualitative range and were, therefore, not used.

Catalog 7030048
Innoko NWR - Tissue 1996

Element	LOD[1] (mg/L)	Duplicate Analyses (Mean RPD[2])	Mean Spike Recovery[3] (%)	Mean SRM[4] Recovery (%)	Maximum Blank	Blank-Based Precision Cutoff[5] (mg/L)
Al		17	95	60	<LOD	200
As		Qualitative[6]	95	93	<LOD	3.0
B		17	95	NCV[7]	<LOD	30
Ba		5	97	NCV	<LOD	5.0
Be		Qualitative	93	NCV	<LOD	0.20
Cd		8	99	95	0.18	1.8
Cr		8	95	57	0.2	2.0
Cu		12	95	95	<LOD	40
Fe		5	94	92	<LOD	40
Hg		4	96	91	<LOD	0.30
Mg		2	97	94	<LOD	20
Mn		9	95	91	<LOD	8.0
Mo		Qualitative	97	NCV	<LOD	10
Ni		17	96	87	0.2	2
Pb		17	97	92	0.04	0.4
Se		10	97	85	<LOD	5.0
Sr		9	97	92	<LOD	3.0
V		5	96	95	<LOD	40
Zn		1	95	96	<LOD	5.0

[1] - Limit of Detection; see table on following page.
[2] - Relative Percent Difference. RPDs <20 are acceptable. N = up to 11.
[3] - Spike recoveries 80% are acceptable. N = up to 11.
[4] - Standard Reference Material. The percent deviation of an SRM analysis result from the certified mean value. Mean SRM values 80% are acceptable. N = up to 11.
[5] - Values greater than the listed figure are considered quantitative data. Values less than the listed figure are considered semi-quantitative or qualitative depending on their relation to the LOD. The figures listed are based on LODs of the kidney analyses.
[6] - At least one duplicate analysis of each pair was in the qualitative range and were, therefore, not used.
[7] - No Certified Value for this analyte.

Catalog 7030048
Limits of Detections

	mg/kg dry weight			
Element	Kidney	Liver	Muscle	Whole Body
Al	20	4	2	5
As	0.3	0.4	0.06	0.4
B	3	0.5	0.7	1
Ba	0.5	0.06	0.06	0.09
Be	0.02	0.02	0.005	0.01
Cd	0.1	0.1	0.03	0.06
Cr	0.2	0.2	0.03	0.04
Cu	4	0.6	0.6	0.8
Fe	4	0.6	0.7	0.7
Hg	0.03	0.03	0.03	0.004
Mg	2	0.2	0.1	0.4
Mn	0.8	0.1	0.2	0.2
Mo	1	0.3	0.4	0.4
Ni	0.09	0.1	0.04	0.06
Pb	0.03	0.04	0.04	0.08
Se	0.5	0.2	0.2	0.2
Sr	0.3	0.07	0.02	0.4
V	4	0.7	0.5	0.9
Zn	0.5	0.08	0.2	0.2

Catalog 7030053
Innoko NWR - Water 1997

Element	LOD[1] (mg/L)	Duplicate Analyses (Mean RPD[2])	Mean Spike Recovery[3] (%)	Mean SRM[4] Recovery (%)	Maximum Blank	Blank-Based Precision Cutoff[5] (mg/L)
Al	0.03	8	95	80	0.04	0.4
As	0.0004	5	86	92	<LOD	0.004
B	0.005	11	97	97	<LOD	0.05
Ba	0.0005	1	90	97	<LOD	0.005
Be	0.0005	Qualitative[6]	98	96	<LOD	0.005
Cd	0.0001	Qualitative	96	98	<LOD	0.001
Cr	0.003	Qualitative	98	94	<LOD	0.03
Cu	0.007	Qualitative	95	99	0.007	0.07
Fe	0.007	1	S/B<1[7]	95	<LOD	0.07
Hg	0.0003	Qualitative	98	98	<LOD	0.003
Mg	0.001	1	98	NCV[8]	0.003	0.03
Mn	0.001	1	93	95	<LOD	0.01
Mo	0.004	Qualitative	98	98	<LOD	0.04
Ni	0.001	6	97	96	<LOD	0.01
Pb	0.01	Qualitative	95	96	<LOD	0.1
Se	0.002	Qualitative	88	92	<LOD	0.02
Sr	0.0006	1	93	97	<LOD	0.006
V	0.007	Qualitative	96	95	<LOD	0.07
Zn	0.006	Qualitative	99	94	<LOD	0.06

[1] - Limit of Detection.
[2] - Relative Percent Difference. RPDs <20 are acceptable. N = up to six.
[3] - Spike recoveries 80% are acceptable. N = up to six.
[4] - Standard Reference Material. The percent deviation of an SRM analysis result from the certified mean value. Mean SRM values 80% are acceptable. N = up to six.
[5] - Values greater than the listed figure are considered quantitative data. Values less than the listed figure are considered semi-quantitative or qualitative depending on their relation to the LOD.
[6] - At least one duplicate analysis of each pair was in the qualitative range and were, therefore, not used.
[7] - Spike/Background ratio <1, therefore, these values were not used.
[8] - No Certified Value for this analyte.

Catalog 7030054
Innoko NWR - Sediment 1997

Element	LOD[1] (mg/L)	Duplicate Analyses (Mean RPD[2])	Mean Spike Recovery[3] (%)	Mean SRM[4] Recovery (%)	Maximum Blank	Blank-Based Precision Cutoff[5] (mg/L)
Al	3.44	12	85	NCV[6]	<LOD	34.4
As	0.487	1	97	92	<LOD	4.87
B	6.69	Qualitative[7]	79	NCV	<LOD	66.9
Ba	0.0625	4	82	NCV	<LOD	0.63
Be	0.688	Qualitative	83	72	<LOD	6.88
Ca	33.4	4	91	NCV	<LOD	334
Cd	0.0242	4	97	89	<LOD	0.24
Cr	0.625	7	77	Fail	<LOD	6.25
Cu	0.312	6	87	95	<LOD	3.12
Fe	6.88	3	80	NCV	9.68	96.8
Hg	0.0111	2	91	96	<LOD	0.11
Mg	6.25	6	92	NCV	<LOD	62.5
Mn	0.669	1	97	84	<LOD	6.69
Mo	0.625	Qualitative	92	62	<LOD	6.25
Na	3.13	8	93	NCV	13.68	137
Ni	0.152	6	85	69	<LOD	1.52
Pb	0.365	2	97	NCV	<LOD	3.65
S	3.13	5	92	82	<LOD	31.3
Se	0.124	4	93	91	<LOD	1.24
Sr	0.0312	8	91	43	<LOD	0.312
V	0.625	6	56	25	<LOD	6.25
Zn	3.44	4	97	75	<LOD	34.4

[1] - Limit of Detection.
[2] - Relative Percent Difference. RPDs <20 are acceptable. N = up to six.
[3] - Spike recoveries 80% are acceptable. N = up to six.
[4] - Standard Reference Material. The percent deviation of an SRM analysis result from the certified mean value. Acceptable Mean SRM values are based on past laboratory performance. N = up to six. See text for further explanation.
[5] - Values greater than the listed figure are considered quantitative data. Values less than the listed figure are considered semi-quantitative or qualitative depending on their relation to the LOD.
[6] - No Certified Value for this analyte.
[7] - At least one duplicate analysis of each pair was in the qualitative range and were, therefore, not used.

Catalog 7030057
Innoko NWR - Tissue1997

Element	LOD[1] (mg/L)	Duplicate Analyses (Mean RPD[2])	Mean Spike Recovery[3] (%)	Mean SRM[4] Recovery (%)	Maximum Blank	Blank-Based Precision Cutoff[5] (mg/L)
Al	5	1	97	87	<LOD	50
As	0.2	15	93	94	<LOD	2
B	1	Qualitative[6]	91	No SRM[7]	2	20
Ba	0.1	0	98	No SRM	0.1	1
Be	0.04	Qualitative	97	No SRM	<LOD	0.4
Cd	0.1	8	99	Qualitative	<LOD	1
Cr	0.8	Qualitative	98	82	<LOD	8
Cu	0.5	5	96	83	<LOD	5
Fe	4	7	96	96	<LOD	40
Hg	0.05	5	94	91	<LOD	0.5
Mg	0.5	2	98	No SRM	1.82	18.2
Mn	1	1	97	85	<LOD	10
Mo	0.7	Qualitative	98	No SRM	<LOD	7
Ni	0.6	Qualitative	97	81	<LOD	6
Pb	0.5	Qualitative	94	No SRM	<LOD	5
Se	0.2	0	86	93	<LOD	2
Sr	0.5	1	95	No SRM	<LOD	5
V	0.6	Qualitative	98	No SRM	<LOD	6
Zn	0.2	1	95	84	<LOD	2
n = up to 4.						

[1] - Limit of Detection.
[2] - Relative Percent Difference. RPDs <20 are acceptable. N = up to four.
[3] - Spike recoveries 80% are acceptable. N = up to four.
[4] - Standard Reference Material. The percent deviation of an SRM analysis result from the certified mean value. Mean SRM values 80% are acceptable. N = up to four.
[5] - Values greater than the listed figure are considered quantitative data. Values less than the listed figure are considered semi-quantitative or qualitative depending on their relation to the LOD.
[6] - At least one duplicate analysis of each pair was in the qualitative range and were, therefore, not used.
[7] - No Certified Value for this analyte.

APPENDIX D: TOTAL METALS CONCENTRATIONS (MG/L) IN STREAM WATER FROM INNOKO NATIONAL WILDLIFE REFUGE AND FROM THE UPPER LITTLE MUD RIVER DRAINAGE, ALASKA, 1996.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
IN091AWT	0.0926	<0.0056	0.023	0.043	<0.0006	<0.0006	<0.0056	<0.0056	0.5674	<0.0003[1]	6.411
IN091BWT	0.0851	<0.0056	0.021	0.044	<0.0006	<0.0006	<0.0056	<0.0056	0.5736	<0.0003	6.793
IN091CWT	0.0803	<0.0056	0.026	0.0429	<0.0006	<0.0006	<0.0056	<0.0056	0.5482	<0.0003	6.512
IN101AWT	0.1843	<0.0056	0.015	0.0414	<0.0006	<0.0006	<0.0056	<0.0056	2.108	<0.0003	4.58
IN101BWT	0.1787	<0.0056	<0.0111	0.041	<0.0006	<0.0006	<0.0056	<0.0056	2.062	<0.0003	4.53
IN101CWT	0.1987	<0.0056	<0.0111	0.0407	<0.0006	<0.0006	<0.0056	<0.0056	2.091	<0.0003	4.481
IN121AWT	2.095	<0.0056	0.013	0.0874	<0.0006	<0.0006	<0.0056	0.0063	4.194	0.0000171	5.009
IN121BWT	2.449	<0.0056	0.014	0.0951	<0.0006	<0.0006	<0.0056	0.0079	4.885	0.0000290	5.39
IN121CWT	2.084	<0.0056	0.024	0.0784	<0.0006	<0.0006	<0.0056	0.0064	3.636	0.0000230	5.171
IN151AWT	3.507	<0.0056	0.013	0.1045	<0.0006	<0.0006	0.0062	0.0095	7.685	0.0000117	3.67
IN151BWT	3.773	<0.0056	<0.0111	0.1065	<0.0006	<0.0006	0.0062	0.0096	7.822	0.0000112	3.745
IN151CWT	2.054	<0.0056	<0.0111	0.0881	<0.0006	<0.0006	<0.0056	0.0082	6.05	0.0000118	3.32
IN161AWT	9.011	0.0077	0.014	0.1587	<0.0006	<0.0006	0.012	0.013	12.07	0.0000482	3.771
IN161BWT	7.895	<0.0056	<0.0111	0.1483	<0.0006	<0.0006	0.0107	0.0123	11.21	0.0000498	3.538
IN161CWT	8.217	<0.0056	0.012	0.1529	<0.0006	<0.0006	0.0107	0.0124	11.48	0.0000462	3.679
IN171AWT	6.662	<0.0056	<0.0111	0.1284	<0.0006	<0.0006	0.0105	0.0145	9.887	<0.0003	3.623
IN171BWT	8.609	<0.0056	0.018	0.1642	<0.0006	<0.0006	0.0122	0.0177	12.44	<0.0003	4.078
IN171CWT	7.525	<0.0056	0.013	0.1512	<0.0006	<0.0006	0.0114	0.0162	11.28	<0.0003	3.78
IN181AWT	1.614	<0.0056	0.016	0.0582	<0.0006	<0.0006	<0.0056	<0.0056	5.495	0.0000115	3.675
IN181BWT	1.413	<0.0056	0.012	0.0581	<0.0006	<0.0006	<0.0056	<0.0056	5.594	0.00000579	3.722
IN181CWT	0.8898	<0.0056	0.013	0.0545	<0.0006	<0.0006	<0.0056	<0.0056	4.989	0.00000612	3.572
IN191AWT	0.4316	<0.0056	0.013	0.0359	<0.0006	<0.0006	<0.0056	<0.0056	3.324	<0.0003	2.818
IN191BWT	0.4595	<0.0056	0.012	0.0352	<0.0006	<0.0006	<0.0056	<0.0056	3.299	<0.0003	2.757
IN191CWT	0.4641	<0.0056	0.014	0.0356	<0.0006	<0.0006	<0.0056	<0.0056	3.262	<0.0003	2.776
IN201AWT	0.0777	<0.0056	<0.0111	0.0093	<0.0006	<0.0006	<0.0056	<0.0056	0.2687	<0.0003	3.76
IN201BWT	0.0708	<0.0056	0.014	0.0089	<0.0006	<0.0006	<0.0056	<0.0056	0.2487	<0.0003	3.66
IN201CWT	0.0724	<0.0056	<0.0111	0.009	<0.0006	<0.0006	<0.0056	<0.0056	0.2529	<0.0003	3.686
IN201DWT	0.0706	<0.0056	<0.0111	0.0088	<0.0006	<0.0006	<0.0056	<0.0056	0.2904	<0.0003	3.608
IN201EWT	0.0888	<0.0056	<0.0111	0.0092	<0.0006	<0.0006	<0.0056	<0.0056	0.25	<0.0003	3.624

Appendix D, cont.

Site	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
IN091AWT	0.0674	<0.0044	<0.0056	<0.0111	<0.0056	0.0677	<0.0044	<0.0111
IN091BWT	0.0686	<0.0044	<0.0056	<0.0111	<0.0056	0.0693	<0.0044	<0.0111
IN091CWT	0.066	<0.0044	<0.0056	<0.0111	<0.0056	0.0673	<0.0044	<0.0111
IN101AWT	0.046	<0.0044	<0.0056	<0.0111	<0.0056	0.0671	<0.0044	<0.0111
IN101BWT	0.0448	<0.0044	<0.0056	<0.0111	<0.0056	0.0665	<0.0044	<0.0111
IN101CWT	0.0452	<0.0044	<0.0056	<0.0111	<0.0056	0.0647	<0.0044	<0.0111
IN121AWT	0.2609	<0.0044	<0.0056	<0.0111	<0.0056	0.0668	0.0066	0.0156
IN121BWT	0.3036	<0.0044	<0.0056	<0.0111	<0.0056	0.07	0.0079	0.018
IN121CWT	0.2065	<0.0044	<0.0056	<0.0111	<0.0056	0.068	0.006	0.0126
IN151AWT	0.17	<0.0044	0.0063	<0.0111	<0.0056	0.0431	0.0117	0.0188
IN151BWT	0.1696	<0.0044	0.0068	<0.0111	<0.0056	0.0439	0.0121	0.015
IN151CWT	0.144	<0.0044	<0.0056	<0.0111	<0.0056	0.0405	0.0094	<0.0111
IN161AWT	0.2825	<0.0044	0.0118	<0.0111	<0.0056	0.046	0.0219	0.0453
IN161BWT	0.2684	<0.0044	0.0111	<0.0111	<0.0056	0.0433	0.0195	0.0427
IN161CWT	0.276	<0.0044	0.0118	<0.0111	<0.0056	0.0447	0.0206	0.0445
IN171AWT	0.2358	<0.0044	0.0111	<0.0111	<0.0056	0.0403	0.0182	0.036
IN171BWT	0.3288	<0.0044	0.0142	<0.0111	<0.0056	0.0443	0.0226	0.0431
IN171CWT	0.3101	<0.0044	0.0129	0.0117	<0.0056	0.0412	0.0206	0.0414
IN181AWT	0.2228	<0.0044	<0.0056	<0.0111	<0.0056	0.0456	0.0057	<0.0111
IN181BWT	0.226	<0.0044	<0.0056	<0.0111	<0.0056	0.046	0.0054	0.0124
IN181CWT	0.2211	<0.0044	<0.0056	<0.0111	<0.0056	0.0451	0.0046	0.0195
IN191AWT	0.0752	<0.0044	<0.0056	<0.0111	<0.0056	0.0375	<0.0044	<0.0111
IN191BWT	0.0733	<0.0044	<0.0056	<0.0111	<0.0056	0.0363	<0.0044	<0.0111
IN191CWT	0.0734	<0.0044	<0.0056	<0.0111	<0.0056	0.0367	<0.0044	<0.0111
IN201AWT	0.0159	<0.0044	<0.0056	<0.0111	<0.0056	0.0364	<0.0044	<0.0111
IN201BWT	0.0154	<0.0044	<0.0056	<0.0111	<0.0056	0.0352	<0.0044	<0.0111
IN201CWT	0.0157	<0.0044	<0.0056	<0.0111	<0.0056	0.0353	<0.0044	<0.0111
IN201DWT	0.0154	<0.0044	<0.0056	<0.0111	<0.0056	0.0348	<0.0044	0.0112
IN201EWT	0.0153	<0.0044	<0.0056	<0.0111	<0.0056	0.0352	<0.0044	<0.0111

Appendix D, cont.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
IN211AWT	0.1411	<0.0056	<0.0111	0.011	<0.0006	<0.0006	<0.0056	<0.0056	0.4725	0.00000873	2.584
IN211BWT	0.1271	<0.0056	<0.0111	0.0105	<0.0006	<0.0006	<0.0056	<0.0056	0.4688	0.00000798	2.598
IN211CWT	0.1273	<0.0056	<0.0111	0.0105	<0.0006	<0.0006	<0.0056	<0.0056	0.452	0.00000854	2.533
IN211DWT	0.1229	<0.0056	<0.0111	0.0107	<0.0006	<0.0006	<0.0056	<0.0056	0.5024	0.00000791	2.595
IN211EWT	0.1434	<0.0056	<0.0111	0.0111	<0.0006	<0.0006	<0.0056	<0.0056	0.479	0.00000818	2.61
IN221AWT	0.319	<0.0056	<0.0111	0.025	<0.0006	<0.0006	<0.0056	<0.0056	2.506	0.000002	3.14
IN221BWT	0.2936	<0.0056	<0.0111	0.0256	<0.0006	<0.0006	<0.0056	<0.0056	2.578	0.00000275	3.226
IN221CWT	0.3042	<0.0056	<0.0111	0.0246	<0.0006	<0.0006	<0.0056	<0.0056	2.5	0.00000207	3.137
IN221DWT	0.3237	<0.0056	<0.0111	0.0246	<0.0006	<0.0006	<0.0056	<0.0056	2.475	<0.0003	3.107
IN221EWT	0.3687	<0.0056	<0.0111	0.0252	<0.0006	<0.0006	<0.0056	<0.0056	2.528	<0.0003	3.174
IN231AWT	0.3315	<0.0056	<0.0111	0.0262	<0.0006	<0.0006	<0.0056	<0.0056	2.521	<0.0003	3.008
IN231BWT	0.3142	<0.0056	<0.0111	0.0252	<0.0006	<0.0006	<0.0056	<0.0056	2.335	<0.0003	2.807
IN231CWT	0.3354	<0.0056	<0.0111	0.0277	<0.0006	<0.0006	<0.0056	<0.0056	2.794	<0.0003	3.223
IN231DWT	0.3328	<0.0056	<0.0111	0.0274	<0.0006	<0.0006	<0.0056	<0.0056	2.761	<0.0003	3.204
IN231EWT	0.3495	<0.0056	<0.0111	0.0267	<0.0006	<0.0006	<0.0056	<0.0056	2.691	<0.0003	3.072
IN241AWT	0.192	0.0146	<0.0111	0.0072	<0.0006	<0.0006	<0.0056	<0.0056	0.2527	<0.0003	7.555
IN241BWT	0.3316	0.0138	<0.0111	0.0093	<0.0006	<0.0006	<0.0056	<0.0056	0.4742	<0.0003	7.343
IN241CWT	0.2017	0.0147	<0.0111	0.0073	<0.0006	<0.0006	<0.0056	<0.0056	0.2751	<0.0003	7.477
IN241DWT	0.1946	0.0135	<0.0111	0.0073	<0.0006	<0.0006	<0.0056	<0.0056	0.2636	<0.0003	7.438
IN241EWT	0.1768	0.014	<0.0111	0.007	<0.0006	<0.0006	<0.0056	<0.0056	0.2474	<0.0003	7.525
IN251AWT	0.1619	0.0161	<0.0111	0.008	<0.0006	<0.0006	<0.0056	<0.0056	0.3819	0.0000121	8.005
IN251BWT	0.173	0.0181	<0.0111	0.0084	<0.0006	<0.0006	<0.0056	<0.0056	0.4059	0.00000997	8.019
IN251CWT	0.1669	0.0182	<0.0111	0.008	<0.0006	<0.0006	<0.0056	<0.0056	0.3857	0.00000105	7.998
IN251DWT	0.1673	0.0151	<0.0111	0.0083	<0.0006	<0.0006	<0.0056	<0.0056	0.3875	<0.0003	8.067
IN251EWT	0.167	0.0183	<0.0111	0.008	<0.0006	<0.0006	<0.0056	<0.0056	0.3877	<0.0003	7.905
IN261AWT	0.2796	<0.0056	<0.0111	0.0281	<0.0006	<0.0006	<.00056	<0.0056	3.627	0.00000312	3.36
IN261BWT	0.3087	<0.0056	<0.0111	0.0292	<0.0006	<0.0006	<0.0056	<0.0056	4.035	0.00000177	3.509
IN261CWT	0.3136	<0.0056	<0.0111	0.028	<0.0006	<0.0006	<0.0056	<0.0056	3.773	0.00000251	3.437

Appendix D, cont.

Site	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
IN211AWT	0.0245	<0.0044	<0.0056	<0.0111	<0.0056	0.032	<0.0044	<0.0111
IN211BWT	0.0242	<0.0044	<0.0056	<0.0111	<0.0056	0.0317	<0.0044	<0.0111
IN211CWT	0.0235	<0.0044	<0.0056	<0.0111	<0.0056	0.0312	<0.0044	<0.0111
IN211DWT	0.0243	<0.0044	<0.0056	<0.0111	<0.0056	0.0318	<0.0044	<0.0111
IN211EWT	0.0247	<0.0044	<0.0056	<0.0111	<0.0056	0.0321	<0.0044	<0.0111
IN221AWT	0.0843	<0.0044	<0.0056	<0.0111	<0.0056	0.0406	<0.0044	<0.0111
IN221BWT	0.0877	<0.0044	<0.0056	<0.0111	<0.0056	0.0413	<0.0044	<0.0111
IN221CWT	0.0841	<0.0044	<0.0056	<0.0111	<0.0056	0.0405	<0.0044	<0.0111
IN221DWT	0.0832	<0.0044	<0.0056	<0.0111	<0.0056	0.04	<0.0044	<0.0111
IN221EWT	0.0854	<0.0044	<0.0056	<0.0111	<0.0056	0.0407	<0.0044	<0.0111
IN231AWT	0.0839	<0.0044	<0.0056	<0.0111	<0.0056	0.0412	<0.0044	<0.0111
IN231BWT	0.0777	<0.0044	<0.0056	<0.0111	<0.0056	0.0396	<0.0044	<0.0111
IN231CWT	0.0914	<0.0044	<0.0056	<0.0111	<0.0056	0.046	<0.0044	<0.0111
IN231DWT	0.0927	<0.0044	<0.0056	<0.0111	<0.0056	0.0455	<0.0044	<0.0111
IN231EWT	0.0874	<0.0044	<0.0056	<0.0111	<0.0056	0.0436	<0.0044	<0.0111
IN241AWT	0.0122	<0.0044	<0.0056	<0.0111	<0.0056	0.0194	<0.0044	<0.0111
IN241BWT	0.0164	<0.0044	<0.0056	<0.0111	<0.0056	0.019	<0.0044	<0.0111
IN241CWT	0.0127	<0.0044	<0.0056	<0.0111	<0.0056	0.0193	<0.0044	<0.0111
IN241DWT	0.0127	<0.0044	<0.0056	<0.0111	<0.0056	0.0188	<0.0044	<0.0111
IN241EWT	0.0126	<0.0044	<0.0056	<0.0111	<0.0056	0.019	<0.0044	<0.0111
IN251AWT	0.0184	<0.0044	<0.0056	<0.0111	<0.0056	0.0239	<0.0044	<0.0111
IN251BWT	0.0186	<0.0044	<0.0056	<0.0111	<0.0056	0.0253	<0.0044	<0.0111
IN251CWT	0.0187	<0.0044	<0.0056	<0.0111	<0.0056	0.0241	<0.0044	<0.0111
IN251DWT	0.0185	<0.0044	<0.0056	<0.0111	<0.0056	0.0244	<0.0044	<0.0111
IN251EWT	0.0185	<0.0044	<0.0056	<0.0111	<0.0056	0.0241	<0.0044	<0.0111
IN261AWT	0.081	<0.0044	<0.0056	<0.0111	<0.0056	0.0403	<0.0044	<0.0111
IN261BWT	0.0874	<0.0044	<0.0056	<0.0111	<0.0056	0.0429	<0.0044	<0.0111
IN261CWT	0.0832	<0.0044	<0.0056	<0.0111	<0.0056	0.0426	<0.0044	<0.0111

Appendix D, cont.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
IN271AWT	0.1325	<0.0056	<0.0111	0.0392	<0.0006	<0.0006	<0.0056	<0.0056	1.737	0.00000364	6.295
IN271BWT	0.1327	<0.0056	0.013	0.0386	<0.0006	<0.0006	<0.0056	<0.0056	1.683	0.00000414	6.152
IN271CWT	0.114	<0.0056	0.012	0.0386	<0.0006	<0.0006	<0.0056	<0.0056	1.751	0.00000268	6.081
IN281AWT	5.229	<0.0056	<0.0111	0.1781	<0.0006	<0.0006	0.008	0.0108	10.38	<0.0003	7.398
IN281BWT	4.81	0.006	0.016	0.1765	<0.0006	<0.0006	0.0081	0.0104	10.27	<0.0003	7.454
IN281CWT	5.716	<0.0056	0.013	0.1822	<0.0006	<0.0006	0.0089	0.0115	10.96	<0.0003	7.692
IN291AWT	0.2732	<0.0056	<0.0111	0.0457	<0.0006	<0.0006	<0.0056	<0.0056	4.355	0.00000722	5.178
IN291BWT	0.2511	0.0057	<0.0111	0.0466	<0.0006	<0.0006	<0.0056	<0.0056	4.314	0.00000643	5.258
IN291CWT	0.3322	0.0058	0.016	0.045	<0.0006	<0.0006	<0.0056	<0.0056	4.459	0.00000623	4.902
IN301AWT	0.348	<0.0056	<0.0111	0.0408	<0.0006	<0.0006	<0.0056	<0.0056	6.311	0.00000209	3.402
IN301BWT	0.4101	<0.0056	<0.0111	0.0409	<0.0006	<0.0006	<0.0056	<0.0056	6.281	0.00000207	3.356
IN301CWT	0.3727	<0.0056	<0.0111	0.0403	<0.0006	<0.0006	<0.0056	<0.0056	6.173	0.00000261	3.306
IN311AWT	0.3765	<0.0056	0.012	0.0338	<0.0006	<0.0006	<0.0056	<0.0056	5.325	<0.0003	2.618
IN311BWT	0.3403	<0.0056	0.018	0.0331	<0.0006	<0.0006	<0.0056	<0.0056	5.257	<0.0003	2.588
IN311CWT	0.3778	<0.0056	0.012	0.0345	<0.0006	<0.0006	<0.0056	<0.0056	5.433	<0.0003	2.69
IN321AWT	0.3266	<0.0056	<0.0111	0.0389	<0.0006	<0.0006	<0.0056	<0.0056	4.002	<0.0003	4.634
IN321BWT	0.3237	<0.0056	<0.0111	0.0393	<0.0006	<0.0006	<0.0056	<0.0056	4.052	<0.0003	4.707
IN321CWT	0.3168	<0.0056	<0.0111	0.0393	<0.0006	<0.0006	<0.0056	<0.0056	4.071	<0.0003	4.699
IN331AWT	0.1944	<0.0056	<0.0111	0.0526	<0.0006	<0.0006	<0.0056	<0.0056	2.379	<0.0003	5.479
IN331BWT	0.2585	<0.0056	<0.0111	0.0546	<0.0006	<0.0006	<0.0056	<0.0056	2.495	<0.0003	5.653
IN331CWT	0.2528	<0.0056	<0.0111	0.0533	<0.0006	<0.0006	<0.0056	<0.0056	2.424	<0.0003	5.513
IN341AWT	2.96	<0.0056	<0.0111	0.0601	<0.0006	<0.0006	0.0061	0.0073	5.395	<0.0003	4.276
IN341BWT	2.885	<0.0056	<0.0111	0.0599	<0.0006	<0.0006	0.0058	0.0081	5.527	<0.0003	4.317
IN341CWT	2.652	<0.0056	<0.0111	0.0588	<0.0006	<0.0006	0.0058	0.0077	5.39	<0.0003	4.298
IN351AWT	0.2102	<0.0056	<0.0111	0.0609	<0.0006	<0.0006	<0.0056	<0.0056	5.053	0.0000313	6.643
IN351BWT	0.2102	<0.0056	0.022	0.0627	<0.0006	<0.0006	<0.0056	<0.0056	5.248	<0.0003	7.018
IN351CWT	0.2176	<0.0056	0.02	0.0615	<0.0006	<0.0006	<0.0056	<0.0056	5.135	<0.0003	6.878

Appendix D, cont.

Site	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
IN271AWT	0.0747	<0.0044	<0.0056	<0.0111	<0.0056	0.0702	<0.0044	<0.0111
IN271BWT	0.0699	<0.0044	<0.0056	<0.0111	<0.0056	0.069	<0.0044	<0.0111
IN271CWT	0.0772	<0.0044	<0.0056	<0.0111	<0.0056	0.069	<0.0044	<0.0111
IN281AWT	0.2242	<0.0044	0.0074	<0.0111	<0.0056	0.1098	0.0181	0.0259
IN281BWT	0.2256	<0.0044	0.0073	<0.0111	<0.0056	0.1103	0.0173	0.0244
IN281CWT	0.2325	<0.0044	0.0089	<0.0111	<0.0056	0.1114	0.0188	0.0258
IN291AWT	0.1577	<0.0044	<0.0056	<0.0111	<0.0056	0.0743	<0.0044	<0.0111
IN291BWT	0.1545	<0.0044	<0.0056	<0.0111	<0.0056	0.0762	<0.0044	<0.0111
IN291CWT	0.1678	<0.0044	<0.0056	<0.0111	<0.0056	0.0713	<0.0044	<0.0111
IN301AWT	0.1363	<0.0044	<0.0056	<0.0111	<0.0056	0.046	0.0055	<0.0111
IN301BWT	0.1345	<0.0044	<0.0056	<0.0111	<0.0056	0.0456	0.0054	<0.0111
IN301CWT	0.1328	<0.0044	<0.0056	<0.0111	<0.0056	0.045	0.0051	<0.0111
IN311AWT	0.0681	<0.0044	<0.0056	<0.0111	<0.0056	0.0656	0.0053	<0.0111
IN311BWT	0.0675	<0.0044	<0.0056	<0.0111	<0.0056	0.064	0.0051	<0.0111
IN311CWT	0.0695	<0.0044	<0.0056	<0.0111	<0.0056	0.0662	0.0053	<0.0111
IN321AWT	0.1118	<0.0044	<0.0056	<0.0111	<0.0056	0.0424	<0.0044	<0.0111
IN321BWT	0.1127	<0.0044	<0.0056	<0.0111	<0.0056	0.0429	<0.0044	<0.0111
IN321CWT	0.1136	<0.0044	<0.0056	<0.0111	<0.0056	0.0436	<0.0044	<0.0111
IN331AWT	0.0619	<0.0044	<0.0056	<0.0111	<0.0056	0.0755	<0.0044	<0.0111
IN331BWT	0.0641	<0.0044	<0.0056	<0.0111	<0.0056	0.0789	<0.0044	0.0199
IN331CWT	0.0626	<0.0044	<0.0056	<0.0111	<0.0056	0.076	<0.0044	<0.0111
IN341AWT	0.1894	<0.0044	0.0074	<0.0111	<0.0056	0.0312	0.0086	0.0152
IN341BWT	0.1921	<0.0044	0.0081	<0.0111	<0.0056	0.0311	0.0084	0.0147
IN341CWT	0.1908	<0.0044	0.0096	<0.0111	<0.0056	0.0312	0.008	0.0141
IN351AWT	0.0682	<0.0044	<0.0056	<0.0111	<0.0056	0.1006	<0.0044	<0.0111
IN351BWT	0.0696	<0.0044	<0.0056	<0.0111	<0.0056	0.1054	<0.0044	0.0172
IN351CWT	0.0684	<0.0044	<0.0056	<0.0111	<0.0056	0.1028	<0.0044	<0.0111

[1] - All mercury analyses listed as <0.0003 were performed by Research Triangle Institute, all other mercury analyses were performed by Frontier Geosciences.

APPENDIX E: DISSOLVED METALS CONCENTRATIONS (MG/L) IN STREAM WATER FROM INNOKO NATIONAL WILDLIFE REFUGE AND FROM THE UPPER LITTLE MUD RIVER DRAINAGE, ALASKA, 1996.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
IN091AWD	0.0574	<0.0056	0.023	0.0413	<0.0006	<0.0006	<0.0056	<0.0056	0.3658	<0.0003	6.309
IN091BWD	0.0574	<0.0056	0.015	0.0421	<0.0006	<0.0006	<0.0056	<0.0056	0.3807	<0.0003	6.641
IN091CWD	0.0556	<0.0056	0.015	0.0426	<0.0006	<0.0006	<0.0056	<0.0056	0.3828	<0.0003	6.645
IN101AWD	0.1332	<0.0056	0.015	0.0395	<0.0006	<0.0006	<0.0056	<0.0056	1.578	<0.0003	4.580
IN101BWD	0.1187	<0.0056	<0.0111	0.0388	<0.0006	<0.0006	<0.0056	<0.0056	1.531	<0.0003	4.471
IN121AWD	0.0558	<0.0056	0.013	0.0340	<0.0006	<0.0006	<0.0056	<0.0056	0.3137	<0.0003	4.500
IN161AWD	0.2640	<0.0056	<0.0111	0.0193	<0.0006	<0.0006	<0.0056	<0.0056	1.379	<0.0003	1.697
IN171AWD	0.2054	<0.0056	<0.0111	0.0175	<0.0006	<0.0006	<0.0056	<0.0056	1.405	<0.0003	1.956
IN191AWD	0.1611	<0.0056	<0.0111	0.0302	<0.0006	<0.0006	<0.0056	<0.0056	2.045	<0.0003	2.697
IN201AWD	0.0626	<0.0056	<0.0111	0.0091	<0.0006	<0.0006	<0.0056	<0.0056	0.1724	<0.0003	3.738
IN201BWD	0.0345	<0.0056	<0.0111	0.0086	<0.0006	<0.0006	<0.0056	<0.0056	0.1383	<0.0003	3.611
IN201CWD	0.0350	<0.0056	<0.0111	0.0086	<0.0006	<0.0006	<0.0056	<0.0056	0.1358	<0.0003	3.679
IN201DWD	0.0340	<0.0056	<0.0111	0.0085	<0.0006	<0.0006	<0.0056	<0.0056	0.1516	<0.0003	3.574
IN201EWD	0.0518	<0.0056	<0.0111	0.0085	<0.0006	<0.0006	<0.0056	<0.0056	0.1272	<0.0003	3.212
IN211AWD	0.0461	<0.0056	<0.0111	0.0094	<0.0006	<0.0006	<0.0056	<0.0056	0.2052	<0.0003	2.573
IN211BWD	0.0659	<0.0056	<0.0111	0.0092	<0.0006	<0.0006	<0.0056	<0.0056	0.2054	<0.0003	2.545
IN211CWD	0.0449	<0.0056	<0.0111	0.0094	<0.0006	<0.0006	<0.0056	<0.0056	0.2086	<0.0003	2.533
IN211DWD	0.0380	<0.0056	<0.0111	0.0092	<0.0006	<0.0006	<0.0056	<0.0056	0.2104	<0.0003	2.578
IN211EWD	0.0381	<0.0056	<0.0111	0.0093	<0.0006	<0.0006	<0.0056	<0.0056	0.2167	<0.0003	2.610
IN221AWD	0.0380	<0.0056	<0.0111	0.0192	<0.0006	<0.0006	<0.0056	<0.0056	0.7873	<0.0003	3.140
IN221BWD	0.0389	<0.0056	<0.0111	0.0192	<0.0006	<0.0006	<0.0056	<0.0056	0.8422	<0.0003	3.131
IN221CWD	0.0356	<0.0056	<0.0111	0.0196	<0.0006	<0.0006	<0.0056	<0.0056	0.8445	<0.0003	3.137
IN231AWD	0.0334	<0.0056	<0.0111	0.0197	<0.0006	<0.0006	<0.0056	<0.0056	0.8213	<0.0003	2.946
IN231BWD	0.0320	<0.0056	<0.0111	0.0194	<0.0006	<0.0006	<0.0056	<0.0056	1.000	<0.0003	2.903
IN231CWD	0.0264	<0.0056	<0.0111	0.0197	<0.0006	<0.0006	<0.0056	<0.0056	0.8685	<0.0003	2.959
IN241AWD	0.0690	0.0153	<0.0111	0.0059	<0.0006	<0.0006	<0.0056	<0.0056	0.0492	<0.0003	7.555
IN241BWD	0.0688	0.0138	<0.0111	0.0059	<0.0006	<0.0006	<0.0056	<0.0056	0.0468	<0.0003	7.343
IN241CWD	0.0511	0.0147	<0.0111	0.0055	<0.0006	<0.0006	<0.0056	<0.0056	0.0353	<0.0003	7.477
IN241DWD	0.0517	0.0135	<0.0111	0.0055	<0.0006	<0.0006	<0.0056	<0.0056	0.0334	<0.0003	7.335
IN241EWD	0.0547	0.0140	<0.0111	0.0059	<0.0006	<0.0006	<0.0056	<0.0056	0.0460	<0.0003	7.250

Appendix E, cont.

Site	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
IN091AWD	0.0607	<0.0044	<0.0056	<0.0111	<0.0056	0.0677	<0.0044	<0.0111
IN091BWD	0.0631	<0.0044	<0.0056	<0.0111	<0.0056	0.0682	<0.0044	<0.0111
IN091CWD	0.0634	<0.0044	<0.0056	<0.0111	<0.0056	0.0673	<0.0044	<0.0111
IN101AWD	0.0422	<0.0044	<0.0056	<0.0111	<0.0056	0.0671	<0.0044	<0.0111
IN101BWD	0.0405	<0.0044	<0.0056	<0.0111	<0.0056	0.0661	<0.0044	<0.0111
IN121AWD	0.0156	<0.0044	<0.0056	<0.0111	<0.0056	0.0616	<0.0044	<0.0111
IN161AWD	0.1050	<0.0044	<0.0056	<0.0111	<0.0056	0.0228	<0.0044	<0.0111
IN171AWD	0.1306	<0.0044	<0.0056	<0.0111	<0.0056	0.0242	<0.0044	<0.0111
IN191AWD	0.0650	<0.0044	<0.0056	<0.0111	<0.0056	0.0353	<0.0044	<0.0111
IN201AWD	0.0158	<0.0044	<0.0056	<0.0111	<0.0056	0.0361	<0.0044	<0.0111
IN201BWD	0.0142	<0.0044	<0.0056	<0.0111	<0.0056	0.0348	<0.0044	<0.0111
IN201CWD	0.0144	<0.0044	<0.0056	<0.0111	<0.0056	0.0353	<0.0044	<0.0111
IN201DWD	0.0141	<0.0044	<0.0056	<0.0111	<0.0056	0.0347	<0.0044	<0.0111
IN201EWD	0.0129	<0.0044	<0.0056	<0.0111	<0.0056	0.0331	<0.0044	<0.0111
IN211AWD	0.0214	<0.0044	<0.0056	<0.0111	<0.0056	0.0317	<0.0044	<0.0111
IN211BWD	0.0213	<0.0044	<0.0056	<0.0111	<0.0056	0.0311	<0.0044	<0.0111
IN211CWD	0.0222	<0.0044	<0.0056	<0.0111	<0.0056	0.0312	<0.0044	<0.0111
IN211DWD	0.0216	<0.0044	<0.0056	<0.0111	<0.0056	0.0316	<0.0044	<0.0111
IN211EWD	0.0220	<0.0044	<0.0056	<0.0111	<0.0056	0.0319	<0.0044	<0.0111
IN221AWD	0.0801	<0.0044	<0.0056	<0.0111	<0.0056	0.0405	<0.0044	<0.0111
IN221BWD	0.0792	<0.0044	<0.0056	<0.0111	<0.0056	0.0403	<0.0044	<0.0111
IN221CWD	0.0794	<0.0044	<0.0056	<0.0111	<0.0056	0.0405	<0.0044	<0.0111
IN231AWD	0.0773	<0.0044	<0.0056	<0.0111	<0.0056	0.0400	<0.0044	<0.0111
IN231BWD	0.0770	<0.0044	<0.0056	<0.0111	<0.0056	0.0401	<0.0044	<0.0111
IN231CWD	0.0776	<0.0044	<0.0056	<0.0111	<0.0056	0.0412	<0.0044	<0.0111
IN241AWD	0.0101	<0.0044	<0.0056	<0.0111	<0.0056	0.0194	<0.0044	<0.0111
IN241BWD	0.0098	<0.0044	<0.0056	<0.0111	<0.0056	0.0190	<0.0044	<0.0111
IN241CWD	0.0091	<0.0044	<0.0056	<0.0111	<0.0056	0.0193	<0.0044	<0.0111
IN241DWD	0.0093	<0.0044	<0.0056	<0.0111	<0.0056	0.0193	<0.0044	0.0142
IN241EWD	0.0094	<0.0044	<0.0056	<0.0111	<0.0056	0.0190	<0.0044	0.0154

Appendix E, cont.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
IN251AWD	0.0543	0.0161	<0.0111	0.0069	<0.0006	<0.0006	<0.0056	<0.0056	0.1245	<0.0003	8.005
IN251BWD	0.0554	0.0137	<0.0111	0.0068	<0.0006	<0.0006	<0.0056	<0.0056	0.1461	<0.0003	7.875
IN251CWD	0.0483	0.0134	<0.0111	0.0065	<0.0006	<0.0006	<0.0056	<0.0056	0.1245	<0.0003	7.998
IN251DWD	0.0493	0.0127	<0.0111	0.0069	<0.0006	<0.0006	<0.0056	<0.0056	0.1277	<0.0003	8.247
IN251EWD	0.0585	0.0144	<0.0111	0.0070	<0.0006	<0.0006	<0.0056	<0.0056	0.1415	<0.0003	7.905
IN261AWD	0.0362	<0.0056	<0.0111	0.0214	<0.0006	<0.0006	<0.0056	<0.0056	0.9753	<0.0003	3.360
IN271AWD	0.0574	<0.0056	<0.0111	0.0358	<0.0006	<0.0006	<0.0056	<0.0056	0.9961	<0.0003	6.201
IN271BWD	0.0564	<0.0056	0.019	0.0363	<0.0006	<0.0006	<0.0056	<0.0056	1.105	<0.0003	6.118
IN271CWD	0.0483	<0.0056	0.012	0.0349	<0.0006	<0.0006	<0.0056	<0.0056	0.8112	<0.0003	6.081
IN291AWD	0.1083	0.0056	<0.0111	0.0443	<0.0006	<0.0006	<0.0056	<0.0056	3.080	<0.0003	5.106
IN301AWD	0.0543	<0.0056	<0.0111	0.0310	<0.0006	<0.0006	<0.0056	<0.0056	2.600	<0.0003	3.318
IN311AWD	0.0619	<0.0056	<0.0111	0.0254	<0.0006	<0.0006	<0.0056	<0.0056	2.600	<0.0003	2.482
IN331AWD	0.0407	<0.0056	<0.0111	0.0465	<0.0006	<0.0006	<0.0056	<0.0056	1.385	<0.0003	5.431
IN351AWD	0.1022	<0.0056	<0.0111	0.0550	<0.0006	<0.0006	<0.0056	<0.0056	3.460	<0.0003	6.643

Site	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
IN251AWD	0.0160	<0.0044	<0.0056	<.0111	<.0056	0.0239	<.0044	<.0111
IN251BWD	0.0181	<0.0044	<0.0056	<.0111	<.0056	0.0235	<.0044	<.0111
IN251CWD	0.0161	<0.0044	<0.0056	<.0111	<.0056	0.0237	<.0044	<.0111
IN251DWD	0.0163	<0.0044	<0.0056	<.0111	<.0056	0.0247	<.0044	<.0111
IN251EWD	0.0160	<0.0044	<0.0056	<.0111	<.0056	0.0241	<.0044	<.0111
IN261AWD	0.0712	<0.0044	<0.0056	<.0111	<.0056	0.0399	<.0044	<.0111
IN271AWD	0.0563	<0.0044	<0.0056	<.0111	<.0056	0.0691	<.0044	<.0111
IN271BWD	0.0693	<0.0044	<0.0056	<.0111	<.0056	0.0689	<.0044	<.0111
IN271CWD	0.0418	<0.0044	<0.0056	<.0111	<.0056	0.0686	<.0044	<.0111
IN291AWD	0.1577	<0.0044	<0.0056	<.0111	<.0056	0.0687	<.0044	<.0111
IN301AWD	0.1307	<0.0044	<0.0056	<.0111	<.0056	0.0446	<.0044	0.0131
IN311AWD	0.0577	<0.0044	<0.0056	<.0111	<.0056	0.0613	<.0044	<.0111
IN331AWD	0.0533	<0.0044	<0.0056	<.0111	<.0056	0.0748	<.0044	<.0111
IN351AWD	0.0631	<0.0044	<0.0056	<.0111	<.0056	0.1006	<.0044	<.0111

APPENDIX F: TOTAL METALS CONCENTRATIONS (MG/L) IN STREAM WATER FROM INNOKO NATIONAL WILDLIFE REFUGE AND FROM THE UPPER LITTLE MUD RIVER DRAINAGE, ALASKA, 1997.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
IN091AWT	0.077	0.00071	0.024	0.0534	<0.0005	<0.0001	<0.003	<0.007	0.544	<0.0003	7.22
IN091BWT	0.030	0.00064	0.018	0.0505	<0.0005	<0.0001	<0.003	<0.007	0.433	<0.0003	7.04
IN091CWT	<0.03	0.00074	0.019	0.0526	<0.0005	<0.0001	<0.003	<0.007	0.529	<0.0003	7.22
IN101AWT	0.040	0.00083	0.010	0.0744	<0.0005	<0.0001	<0.003	<0.007	2.64	<0.0003	7.27
IN101BWT	0.030	0.0011	0.010	0.0746	<0.0005	<0.0001	<0.003	<0.007	2.64	<0.0003	7.29
IN101CWT	0.050	0.00091	0.011	0.0744	<0.0005	<0.0001	<0.003	<0.007	2.69	<0.0003	7.13
IN121AWT	<0.03	0.00091	0.018	0.0715	<0.0005	<0.0001	<0.003	<0.007	0.976	<0.0003	6.22
IN121BWT	<0.03	0.0009	0.020	0.0712	<0.0005	<0.0001	<0.003	<0.007	1.04	<0.0003	6.58
IN121CWT	<0.03	0.00097	0.020		<0.0005	<0.0001	<0.003	<0.007	0.989	<0.0003	6.27
IN151AWT	0.14	0.0012	<0.005	0.0956	<0.0005	<0.0001	<0.003	<0.007	5.01	<0.0003	4.39
IN151BWT	0.15	0.0012	0.005	0.0954	<0.0005	<0.0001	<0.003	<0.007	5.05	<0.0003	4.41
IN151CWT	0.14	0.0013	<0.005	0.0946	<0.0005	<0.0001	<0.003	<0.007	5.01	<0.0003	4.42
IN161AWT	0.084	0.0012	0.005	0.0460	<0.0005	<0.0001	<0.003	<0.007	3.61	<0.0003	6.53
IN161BWT	0.087	0.0011	0.006	0.0448	<0.0005	<0.0001	<0.003	<0.007	3.55	<0.0003	6.45
IN161CWT	0.075	0.0011	<0.005	0.0450	<0.0005	<0.0001	<0.003	<0.007	3.58	<0.0003	6.56
IN171AWT	0.099	0.00067	0.005	0.0376	<0.0005	<0.0001	<0.003	<0.007	1.07	<0.0003	5.42
IN171BWT	0.15	0.0006	<0.005	0.0383	<0.0005	<0.0001	<0.003	<0.007	1.10	<0.0003	5.45
IN171CWT	0.13	0.00058	0.005	0.0381	<0.0005	<0.0001	<0.003	<0.007	1.08	<0.0003	5.44
IN181AWT	0.65	0.0013	0.007	0.0529	<0.0005	<0.0001	<0.003	<0.007	4.12	<0.0003	4.29
IN181BWT	0.65	0.0011	0.0083	0.0520	<0.0005	<0.0001	<0.003	<0.007	4.04	<0.0003	4.20
IN181CWT	0.65	0.0012	0.007	0.0526	<0.0005	<0.0001	<0.003	<0.007	4.09	<0.0003	4.27
IN191AWT	0.25	0.0036	<0.005	0.0514	<0.0005	<0.0001	<0.003	<0.007	4.43	<0.0003	4.77
IN191BWT	0.24	0.0035	<0.005	0.0513	<0.0005	<0.0001	<0.003	<0.007	4.43	<0.0003	4.76
IN191CWT	0.19	0.0034	<0.005	0.0506	<0.0005	<0.0001	<0.003	<0.007	4.37	<0.0003	4.74
IN261AWT	0.16	0.0029	<0.005	0.0337	<0.0005	<0.0001	<0.003	<0.007	4.08	<0.0003	4.06
IN261BWT	0.17	0.0030	<0.005	0.0338	<0.0005	<0.0001	<0.003	<0.007	4.09	<0.0003	4.06
IN261CWT	<0.03	0.0030	<0.005	0.0344	<0.0005	<0.0001	<0.003	<0.007	4.12	<0.0003	4.06
IN271AWT	0.097	0.0014	0.012	0.0468	<0.0005	<0.0001	<0.003	<0.007	1.65	<0.0003	7.05
IN271BWT	0.087	0.0014	0.013	0.0480	<0.0005	<0.0001	<0.003	<0.007	1.70	<0.0003	7.22
IN271CWT	0.094	0.0012	0.012	0.0475	<0.0005	<0.0001	<0.003	<0.007	1.69	<0.0003	7.14

Appendix F, cont.

Site	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
IN091AWT	0.067	<0.004	0.002	<0.01	<0.002	0.0811	<0.007	<0.006
IN091BWT	0.058	<0.004	0.001	<0.01	<0.002	0.0790	<0.007	<0.006
IN091CWT	0.065	<0.004	0.002	<0.01	<0.002	0.0801	<0.007	<0.006
IN101AWT	0.074	<0.004	0.001	<0.01	<0.002	0.1190	<0.007	<0.006
IN101BWT	0.074	<0.004	0.001	<0.01	<0.002	0.1190	<0.007	<0.006
IN101CWT	0.074	<0.004	0.001	<0.01	<0.002	0.1200	<0.007	<0.006
IN121AWT	0.078	<0.004	<0.001	<0.01	<0.002	0.0926	<0.007	<0.006
IN121BWT	0.083	<0.004	<0.001	<0.01	<0.002	0.0964	<0.007	<0.006
IN121CWT	0.0784	<0.004	<0.001	<0.01	<0.002	0.0923	<0.007	<0.006
IN151AWT	0.245	<0.004	0.002	<0.01	<0.002	0.0709	<0.007	<0.006
IN151BWT	0.248	<0.004	0.002	<0.01	<0.002	0.0704	<0.007	<0.006
IN151CWT	0.246	<0.004	0.002	<0.01	<0.002	0.0702	<0.007	<0.006
IN161AWT	0.096	<0.004	0.002	<0.01	<0.002	0.0691	<0.007	<0.006
IN161BWT	0.094	<0.004	0.002	0.01	<0.002	0.0679	<0.007	<0.006
IN161CWT	0.095	<0.004	0.001	<0.01	<0.002	0.0691	<0.007	<0.006
IN171AWT	0.070	<0.004	0.001	<0.01	<0.002	0.0701	<0.007	<0.006
IN171BWT	0.072	<0.004	<0.001	<0.01	<0.002	0.0703	<0.007	<0.006
IN171CWT	0.070	<0.004	<0.001	<0.01	<0.002	0.0704	<0.007	<0.006
IN181AWT	0.219	<0.004	0.002	<0.01	<0.002	0.0590	<0.007	<0.006
IN181BWT	0.215	<0.004	0.002	<0.01	<0.002	0.0577	<0.007	<0.006
IN181CWT	0.218	<0.004	0.002	<0.01	<0.002	0.0588	<0.007	<0.006
IN191AWT	0.141	<0.004	0.002	<0.01	<0.002	0.0659	<0.007	<0.006
IN191BWT	0.141	<0.004	0.002	<0.01	<0.002	0.0658	<0.007	<0.006
IN191CWT	0.139	<0.004	0.002	<0.01	<0.002	0.0657	<0.007	<0.006
IN261AWT	0.170	<0.004	<0.001	<0.01	<0.002	0.0523	<0.007	<0.006
IN261BWT	0.170	<0.004	<0.001	<0.01	<0.002	0.0526	<0.007	<0.006
IN261CWT	0.171	<0.004	<0.001	<0.01	<0.002	0.0524	<0.007	<0.006
IN271AWT	0.070	<0.004	0.001	<0.01	<0.002	0.0838	<0.007	<0.006
IN271BWT	0.072	<0.004	0.001	<0.01	<0.002	0.0847	<0.007	<0.006
IN271CWT	0.072	<0.004	0.001	<0.01	<0.002	0.0838	<0.007	<0.006

Appendix F, cont.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
IN281AWT	0.38	0.0016	0.005	0.0846	<0.0005	<0.0001	<0.003	<0.007	4.94	<0.0003	7.31
IN281BWT	0.38	0.0017	0.005	0.0856	<0.0005	0.0002	<0.003	<0.007	5.01	<0.0003	7.38
IN281CWT	0.35	0.0016	0.006	0.0845	<0.0005	<0.0001	<0.003	<0.007	4.96	<0.0003	7.33
IN291AWT	0.48	0.0059	0.009	0.0682	<0.0005	<0.0001	<0.003	<0.007	5.70	<0.0003	6.05
IN291BWT	0.48	0.0060	0.007	0.0683	<0.0005	<0.0001	<0.003	<0.007	5.68	<0.0003	5.99
IN291CWT	0.52	0.0053	0.008	0.0679	<0.0005	<0.0001	<0.003	<0.007	5.32	<0.0003	6.15
IN301AWT	2.7	0.0033	<0.005	0.0658	<0.0005	<0.0001	<0.003	<0.007	6.81	<0.0003	3.20
IN301CWT	2.78	0.0031	<0.005	0.0662	<0.0005	<0.0001	<0.003	0.0071	6.91	<0.0003	3.13
IN311AWT	0.52	0.0037	<0.005	0.0430	<0.0005	<0.0001	<0.003	<0.007	6.09	<0.0003	3.23
IN311BWT	0.50	0.0039	<0.005	0.0418	<0.0005	<0.0001	<0.003	<0.007	5.91	<0.0003	3.18
IN311CWT	0.53	0.0039	<0.005	0.0438	<0.0005	<0.0001	<0.003	<0.007	6.15	<0.0003	3.32
IN321AWT	0.575	0.0037	<0.005	0.0489	<0.0005	<0.0001	<0.003	<0.007	5.38	<0.0003	5.23
IN321BWT	0.53	0.0038	<0.005	0.0487	<0.0005	<0.0001	<0.003	<0.007	5.48	<0.0003	5.09
IN321CWT	0.36	0.0030	<0.005	0.0387	<0.0005	<0.0001	<0.003	<0.007	4.37	<0.0003	4.16
IN331AWT	0.12	0.00045	0.005	0.0621	<0.0005	<0.0001	<0.003	<0.007	0.884	<0.0003	6.79
IN331BWT	0.11	0.00039	0.007	0.0609	<0.0005	<0.0001	<0.003	<0.007	0.863	<0.0003	6.67
IN331CWT	0.11	0.00044	0.006	0.0600	<0.0005	<0.0001	<0.003	<0.007	0.849	<0.0003	6.66
IN341AWT	0.14	0.00094	0.014	0.0369	<0.0005	<0.0001	<0.003	<0.007	2.41	<0.0003	13.2
IN341BWT	0.15	0.0011	0.014	0.0377	<0.0005	<0.0001	<0.003	<0.007	2.55	<0.0003	13.2
IN341CWT	0.14	0.0011	0.013	0.0371	<0.0005	<0.0001	<0.003	<0.007	2.51	<0.0003	13.1
IN351AWT	0.12	0.0049	0.011	0.0756	<0.0005	<0.0001	<0.003	<0.007	5.54	<0.0003	8.12
IN351BWT	0.11	0.0039	0.009	0.0595	<0.0005	<0.0001	<0.003	<0.007	4.39	<0.0003	6.36
IN351CWT	0.13	0.0047	0.011	0.0756	<0.0005	<0.0001	<0.003	<0.007	5.47	<0.0003	8.10
IN371AWT	0.469	0.0031	0.008	0.0648	<0.0005	<0.0001	<0.003	<0.007	4.37	<0.0003	5.42
IN371BWT	0.484	0.0051	0.011	0.0996	<0.0005	<0.0001	<0.003	<0.007	6.47	<0.0003	8.39
IN371CWT	0.498	0.0049	0.010	0.0956	<0.0005	<0.0001	<0.003	<0.007	6.19	<0.0003	8.05

Appendix F, cont.

Site	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
IN281AWT	0.145	<0.004	0.001	<0.01	<0.002	0.127	<0.007	<0.006
IN281BWT	0.147	<0.004	0.002	<0.01	<0.002	0.129	<0.007	<0.006
IN281CWT	0.145	<0.004	0.002	<0.01	<0.002	0.128	<0.007	<0.006
IN291AWT	0.345	<0.004	0.002	<0.01	<0.002	0.102	<0.007	<0.006
IN291BWT	0.346	<0.004	0.002	<0.01	<0.002	0.102	<0.007	<0.006
IN291CWT	0.305	<0.004	0.002	<0.01	<0.002	0.103	<0.007	<0.006
IN301AWT	0.140	<0.004	0.002	<0.01	<0.002	0.0458	<0.007	<0.006
IN301CWT	0.140	<0.004	0.002	<0.01	<0.002	0.0456	<0.007	0.0061
IN311AWT	0.062	<0.004	0.001	<0.01	<0.002	0.0816	<0.007	<0.006
IN311BWT	0.059	<0.004	0.002	<0.01	<0.002	0.0797	<0.007	<0.006
IN311CWT	0.063	<0.004	0.001	<0.01	<0.002	0.0832	<0.007	<0.006
IN321AWT	0.131	0.004	0.003	<0.01	<0.002	0.0496	<0.007	<0.006
IN321BWT	0.130	<0.004	0.004	<0.01	<0.002	0.0496	<0.007	<0.006
IN321CWT	0.106	<0.004	0.003	<0.01	<0.002	0.0401	<0.007	<0.006
IN331AWT	0.045	<0.004	0.001	<0.01	<0.002	0.0999	<0.007	<0.006
IN331BWT	0.044	<0.004	0.001	<0.01	<0.002	0.0979	<0.007	<0.006
IN331CWT	0.043	<0.004	0.001	<0.01	<0.002	0.0972	<0.007	<0.006
IN341AWT	0.107	<0.004	0.002	<0.01	<0.002	0.0904	<0.007	<0.006
IN341BWT	0.113	<0.004	0.001	<0.01	<0.002	0.0905	<0.007	<0.006
IN341CWT	0.111	<0.004	0.002	<0.01	<0.002	0.0894	<0.007	<0.006
IN351AWT	0.163	<0.004	0.004	<0.01	<0.002	0.128	<0.007	<0.006
IN351BWT	0.128	<0.004	0.003	<0.01	<0.002	0.100	<0.007	<0.006
IN351CWT	0.160	<0.004	0.004	<0.01	<0.002	0.127	<0.007	<0.006
IN371AWT	0.075	<0.004	0.002	<0.01	<0.002	0.0808	<0.007	<0.006
IN371BWT	0.115	<0.004	0.004	<0.01	<0.002	0.126	<0.007	<0.006
IN371CWT	0.111	<0.004	0.004	<0.01	<0.002	0.121	<0.007	<0.006

APPENDIX G: DISSOLVED METALS CONCENTRATIONS (MG/L) IN STREAM WATER FROM INNOKO NATIONAL WILDLIFE REFUGE AND FROM THE UPPER LITTLE MUD RIVER DRAINAGE, ALASKA, 1997.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
IN091AWD	<0.03	0.0006	0.024	0.0511	<0.0005	<0.0001	<0.003	<0.007	0.4	<0.0003	7.05
IN091BWD	<0.03	0.00064	0.018	0.0505	<0.0005	<0.0001	<0.003	<0.007	0.4	<0.0003	7.04
IN091CWD	<0.03	0.0007	0.019	0.0505	<0.0005	<0.0001	<0.003	<0.007	0.39	<0.0003	7.11
IN101AWD	<0.03	0.0008	0.01	0.0717	<0.0005	<0.0001	<0.003	<0.007	1.76	<0.0003	7.2
IN101BWD	<0.03	0.0006	0.01	0.0705	<0.0005	<0.0001	<0.003	<0.007	1.69	<0.0003	7.16
IN101CWD	<0.03	0.0008	0.01	0.0729	<0.0005	<0.0001	<0.003	<0.007	1.84	<0.0003	7.13
IN121AWD	<0.03	0.0008	0.018	0.0715	<0.0005	<0.0001	<0.003	<0.007	0.784	<0.0003	6.16
IN121BWD	<0.03	0.0008	0.019	0.0712	<0.0005	<0.0001	<0.003	<0.007	0.805	<0.0003	6.27
IN121CWD	<0.03	0.0006	0.02	0.0704	<0.0005	<0.0001	<0.003	<0.007	0.794	<0.0003	6.25
IN151AWD	<0.03	0.00086	<0.005	0.0931	<0.0005	<0.0001	<0.003	<0.007	2.37	<0.0003	4.37
IN151BWD	0.03	0.00092	0.005	0.094	<0.0005	<0.0001	<0.003	<0.007	2.11	<0.0003	4.4
IN151CWD	<0.03	0.00085	<0.005	0.0936	<0.0005	<0.0001	<0.003	<0.007	2.23	<0.0003	4.42
IN161AWD	0.03	0.00087	0.005		<0.0005	<0.0001	<0.003	<0.007	2.65	<0.0003	7
IN161BWD	0.03	0.00089	<0.005		<0.0005	<0.0001	<0.003	<0.007	2.73	<0.0003	6.43
IN161CWD	<0.03	0.00082	<0.005		<0.0005	<0.0001	<0.003	<0.007	2.85	<0.0003	6.52
IN171AWD	<0.03	0.0006	<0.005	0.035	<0.0005	<0.0001	<0.003	<0.007	0.759	<0.0003	5.34
IN171BWD	<0.03	0.0006	<0.005	0.036	<0.0005	<0.0001	<0.003	<0.007	0.744	<0.0003	5.44
IN171CWD	<0.03	0.0005	0.005	0.036	<0.0005	<0.0001	<0.003	<0.007	0.742	<0.0003	5.43
IN181AWD	<0.03	0.00072	0.01	0.0422	<0.0005	<0.0001	<0.003	<0.007	2.39	<0.0003	4.13
IN181BWD	<0.03	0.00086	0.007	0.042	<0.0005	<0.0001	<0.003	<0.007	2.42	<0.0003	4.17
IN181CWD	<0.03	0.00087	0.005	0.0417	<0.0005	<0.0001	<0.003	<0.007	2.4	<0.0003	4.15
IN191AWD	0.056	0.0026	<0.005	0.0457	<0.0005	<0.0001	<0.003	<0.007	2.95	<0.0003	4.64
IN191BWD	0.05	0.0024	<0.005	0.0454	<0.0005	<0.0001	<0.003	<0.007	2.8	<0.0003	4.65
IN191CWD	0.06	0.0025	<0.005	0.0454	<0.0005	<0.0001	<0.003	<0.007	2.88	<0.0003	4.65
IN261AWD	<0.03	0.0018	<0.005	0.0287	<0.0005	<0.0001	<0.003	<0.007	1.95	<0.0003	3.91
IN261BWD	<0.03	0.0019	<0.005	0.0291	<0.0005	<0.0001	<0.003	<0.007	2.04	<0.0003	3.95
IN261CWD	<0.03	0.0019	<0.005	0.0293	<0.0005	<0.0001	<0.003	<0.007	2.07	<0.0003	3.99

Appendix G, cont.

Site	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
IN091AWD	0.059	<0.004	0.001	<0.01	<0.002	0.0804	<0.007	<0.006
IN091BWD	0.058	<0.004	0.001	<0.01	<0.002	0.079	<0.007	<0.006
IN091CWD	0.057	<0.004	0.002	<0.01	<0.002	0.0792	<0.007	<0.006
IN101AWD	0.07	<0.004	0.001	<0.01	<0.002	0.119	<0.007	<0.006
IN101BWD	0.07	<0.004	0.001	<0.01	<0.002	0.116	<0.007	<0.006
IN101CWD	0.071	<0.004	0.001	<0.01	<0.002	0.12	<0.007	<0.006
IN121AWD	0.074	<0.004	<0.001	<0.01	<0.002	0.0921	<0.007	<0.006
IN121BWD	0.076	<0.004	<0.001	<0.01	<0.002	0.0932	<0.007	<0.006
IN121CWD	0.076	<0.004	<0.001	<0.01	<0.002	0.0923	<0.007	<0.006
IN151AWD	0.239	<0.004	0.001	<0.01	<0.002	0.07	<0.007	<0.006
IN151BWD	0.235	<0.004	0.002	<0.01	<0.002	0.0696	<0.007	<0.006
IN151CWD	0.236	<0.004	0.002	<0.01	<0.002	0.07	<0.007	<0.006
IN161AWD	0.088	<0.004	0.002	<0.01	<0.002	0.0669	<0.007	<0.006
IN161BWD	0.089	<0.004	0.002	<0.01	<0.002	0.0677	<0.007	<0.006
IN161CWD	0.09	<0.004	0.002	<0.01	<0.002	0.0688	<0.007	<0.006
IN171AWD	0.061	<0.004	<0.001	<0.01	<0.002	0.0686	<0.007	<0.006
IN171BWD	0.062	<0.004	<0.001	<0.01	<0.002	0.07	<0.007	<0.006
IN171CWD	0.062	<0.004	<0.001	<0.01	<0.002	0.0697	<0.007	<0.006
IN181AWD	0.208	<0.004	0.002	<0.01	<0.002	0.0562	<0.007	<0.006
IN181BWD	0.21	<0.004	0.001	<0.01	<0.002	0.0571	<0.007	<0.006
IN181CWD	0.209	<0.004	0.001	<0.01	<0.002	0.057	<0.007	<0.006
IN191AWD	0.131	<0.004	0.002	<0.01	<0.002	0.0641	<0.007	<0.006
IN191BWD	0.13	<0.004	0.002	<0.01	<0.002	0.0645	<0.007	<0.006
IN191CWD	0.13	<0.004	0.002	<0.01	<0.002	0.0638	<0.007	<0.006
IN261AWD	0.158	<0.004	<0.001	<0.01	<0.002	0.0503	<0.007	<0.006
IN261BWD	0.159	<0.004	<0.001	<0.01	<0.002	0.0508	<0.007	<0.006
IN261CWD	0.162	<0.004	<0.001	<0.01	<0.002	0.0514	<0.007	<0.006

Appendix G, cont.

Site	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
IN271AWD	<0.03	0.0012	0.01	0.0449	<0.0005	<0.0001	<0.003	<0.007	1.14	<0.0003	7.12
IN271BWD	<0.03	0.00093	0.012	0.0453	<0.0005	<0.0001	<0.003	<0.007	1.11	<0.0003	7.22
IN271CWD	<0.03	0.00091	0.012	0.0439	<0.0005	<0.0001	<0.003	<0.007	1.14	<0.0003	6.98
IN281AWD	<0.03	0.0011	<0.005	0.0764	<0.0005	<0.0001	<0.003	<0.007	3.35	<0.0003	7.32
IN281BWD	<0.03	0.0015	0.004	0.0763	<0.0005	<0.0001	<0.003	<0.007	3.24	<0.0003	7.34
IN281CWD	<0.03	0.0011	0.006	0.0749	<0.0005	<0.0001	<0.003	<0.007	3.13	<0.0003	7.23
IN291AWD	<0.03	0.0032	0.007	0.0545	<0.0005	<0.0001	<0.003	<0.007	3.17	<0.0003	6.14
IN291BWD	<0.03	0.0035	0.008	0.0564	<0.0005	<0.0001	<0.003	<0.007	3.08	<0.0003	6.09
IN291CWD	0.03	0.0032	0.009	0.0548	<0.0005	<0.0001	<0.003	<0.007	3.15	<0.0003	6.12
IN301AWD	0.059	0.0016	<0.005	0.031	<0.0005	<0.0001	<0.003	<0.007	2.66	<0.0003	2.94
IN301BWD	0.067	0.0018	<0.005	0.0313	<0.0005	<0.0001	<0.003	<0.007	2.66	<0.0003	2.96
IN301CWD	0.065	0.0015	<0.005	0.0305	<0.0005	<0.0001	<0.003	<0.007	2.58	<0.0003	2.81
IN311AWD	0.042	0.0023	<0.005	0.0328	<0.0005	<0.0001	<0.003	<0.007	3.31	<0.0003	3.15
IN311BWD	0.039	0.0026	<0.005	0.0328	<0.0005	<0.0001	<0.003	<0.007	3.48	<0.0003	3.17
IN311CWD	0.03	0.0024	<0.005	0.0336	<0.0005	<0.0001	<0.003	<0.007	3.44	<0.0003	3.22
IN321AWD	0.094	0.0026	<0.005	0.0397	<0.0005	<0.0001	<0.003	<0.007	3.59	<0.0003	5.15
IN321BWD	0.083	0.0027	<0.005	0.039	<0.0005	<0.0001	<0.003	<0.007	3.48	<0.0003	5.09
IN321CWD	0.077	0.0026	0.005	0.0393	<0.0005	<0.0001	<0.003	<0.007	3.31	<0.0003	5.02
IN331AWD	0.031	<0.0004	0.0075	0.0602	<0.0005	<0.0001	<0.003	<0.007	0.697	<0.0003	6.74
IN331BWD	0.023	0.00032	0.0072	0.0596	<0.0005	<0.0001	<0.003	<0.007	0.676	<0.0003	6.73
IN331CWD	0.041	0.00046	0.006	0.0606	<0.0005	<0.0001	<0.003	<0.007	0.697	<0.0003	6.82
IN341AWD	0.022	0.0033	0.013	0.0351	<0.0005	<0.0001	<0.003	<0.007	1.91	<0.0003	13.2
IN341BWD	0.036	0.00085	0.013	0.0363	<0.0005	<0.0001	<0.003	<0.007	2.26	<0.0003	13.1
IN341CWD	0.026	0.001	0.011	0.0346	<0.0005	<0.0001	<0.003	<0.007	1.96	<0.0003	13
IN351AWD	0.07	0.0043	0.01	0.0709	<0.0005	<0.0001	<0.003	<0.007	4.56	<0.0003	7.95
IN351BWD	0.072	0.0043	0.012	0.0714	<0.0005	<0.0001	<0.003	<0.007	4.54	<0.0003	8.01
IN351CWD	0.076	0.0043	0.011	0.0712	<0.0005	<0.0001	<0.003	<0.007	4.41	<0.0003	8.01
IN371AWD	0.08	0.0044	0.01	0.0879	<0.0005	<0.0001	<0.003	<0.007	5.06	<0.0003	8.21
IN371BWD	0.056	0.0046	0.009	0.088	<0.0005	<0.0001	<0.003	<0.007	5	<0.0003	8.3
IN371CWD	0.074	0.0043	0.011	0.0874	<0.0005	<0.0001	<0.003	<0.007	5.07	<0.0003	8.17

Appendix G, cont.

Site	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
IN271AWD	0.0646	<0.004	0.001	<0.01	<0.002	0.0838	<0.007	<0.006
IN271BWD	0.0629	<0.004	0.001	<0.01	<0.002	0.0849	<0.007	<0.006
IN271CWD	0.0628	<0.004	0.001	<0.01	<0.002	0.0821	<0.007	<0.006
IN281AWD	0.139	<0.004	0.001	<0.01	<0.002	0.128	<0.007	<0.006
IN281BWD	0.14	<0.004	0.001	<0.01	<0.002	0.128	<0.007	<0.006
IN281CWD	0.138	<0.004	0.001	<0.01	<0.002	0.126	<0.007	<0.006
IN291AWD	0.191	<0.004	0.002	<0.01	<0.002	0.103	<0.007	<0.006
IN291BWD	0.275	<0.004	0.002	<0.01	<0.002	0.103	<0.007	<0.006
IN291CWD	0.21	<0.004	0.001	<0.01	<0.002	0.102	<0.007	<0.006
IN301AWD	0.118	<0.004	0.001	<0.01	<0.002	0.0412	<0.007	<0.006
IN301BWD	0.118	<0.004	0.001	<0.01	<0.002	0.0415	<0.007	<0.006
IN301CWD	0.116	<0.004	0.002	<0.01	<0.002	0.04	<0.007	<0.006
IN311AWD	0.0539	<0.004	0.001	<0.01	<0.002	0.0795	<0.007	<0.006
IN311BWD	0.0537	<0.004	0.001	<0.01	<0.002	0.0788	<0.007	<0.006
IN311CWD	0.0539	<0.004	0.001	<0.01	<0.002	0.0807	<0.007	<0.006
IN321AWD	0.121	0.004	0.003	<0.01	<0.002	0.048	<0.007	<0.006
IN321BWD	0.12	<0.004	0.003	<0.01	<0.002	0.047	<0.007	<0.006
IN321CWD	0.122	<0.004	0.003	<0.01	<0.002	0.0478	<0.007	<0.006
IN331AWD	0.0386	<0.004	0.001	<0.01	<0.002	0.0993	<0.007	<0.006
IN331BWD	0.0375	<0.004	0.001	<0.01	<0.002	0.099	<0.007	<0.006
IN331CWD	0.0396	<0.004	0.002	<0.01	<0.002	0.0995	<0.007	<0.006
IN341AWD	0.104	<0.004	0.002	<0.01	<0.002	0.0905	<0.007	<0.006
IN341BWD	0.116	<0.004	0.002	<0.01	<0.002	0.0894	<0.007	<0.006
IN341CWD	0.105	<0.004	0.002	<0.01	<0.002	0.0886	<0.007	<0.006
IN351AWD	0.155	<0.004	0.0036	<0.01	<0.002	0.125	<0.007	<0.006
IN351BWD	0.155	<0.004	0.004	<0.01	<0.002	0.125	<0.007	<0.006
IN351CWD	0.154	<0.004	0.0038	<0.01	<0.002	0.125	<0.007	<0.006
IN371AWD	0.108	<0.004	0.0034	<0.01	<0.002	0.123	<0.007	<0.006
IN371BWD	0.108	<0.004	0.0032	<0.01	<0.002	0.124	<0.007	<0.006
IN371CWD	0.106	<0.004	0.0033	<0.01	<0.002	0.123	<0.007	<0.006

APPENDIX H: METALS CONCENTRATIONS (MG/KG DRY WEIGHT) IN STREAM SEDIMENT FROM INNOKO NATIONAL WILDLIFE REFUGE AND FROM THE UPPER LITTLE MUD RIVER DRAINAGE, ALASKA, 1996.

Site	Rep.	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
09	A	15200	8.91	14.2	304	0.3983	0.7773	42.38	24.08	27088	0.1262	7545
09	B	16290	9.94	15.8	315	0.4156	0.7799	43.36	25.10	29223	0.1292	8574
09	C	14590	9.07	15.3	297	0.4231	0.7876	44.52	23.76	28435	0.1096	7404
10	A	13510	4.13	12.6	195	0.3837	0.5427	35.21	15.78	23328	<0.1059	4912
10	B	9909	3.13	8.36	142	0.2994	0.3515	18.93	10.10	16567	<0.1059	3332
10	C	16450	4.85	12.2	205	0.3782	0.6074	31.17	19.84	23765	<0.1059	5769
12	A	18170	10.97	14.3	302	0.4097	0.7285	33.99	27.20	26128	0.1151	6889
12	B	17350	9.57	14.2	274	0.4003	0.6915	35.27	24.72	25054	<0.1059	7035
12	C	17150	9.28	12.1	277	0.3874	0.6848	34.10	24.64	25040	<0.1059	6874
15	A	19140	6.77	10.8	275	0.3746	0.81	29.08	23.61	25534	<0.1059	5920
15	B	18120	6.85	10.2	278	0.3913	0.8062	30.61	25.32	24968	<0.1059	5920
15	C	17830	6.45	11.3	301	0.3987	0.913	31.19	26.16	25140	<0.1059	6250
16	A	16900	8.91	10.3	232	0.6049	0.8143	24.79	19.74	21788	0.1095	4797
16	B	16280	6.98	8.50	200	0.4671	0.6408	21.87	13.99	19288	<0.1059	4815
16	C	9329	7.25	8.59	133	0.5358	0.5355	17.63	8.156	17999	<0.1059	2183
17	A	15960	4.90	10.9	216	0.3562	0.774	24.21	22.67	22103	<0.1059	5286
17	B	15540	5.12	8.53	223	0.3791	0.804	25.22	24.92	22554	<0.1059	5083
17	C	16200	4.76	7.95	215	0.3523	0.7793	23.94	22.28	22110	<0.1059	5165
18	A	21550	6.65	10.2	264	0.4448	1.154	32.70	27.65	28306	<0.1059	6234
18	B	23070	7.07	10.8	273	0.4549	1.182	34.43	29.32	29624	<0.1059	6359
18	C	20610	6.83	10.1	262	0.4358	1.152	32.29	27.95	28707	<0.1059	6068
19	A	13850	7.31	7.86	299	0.388	0.6245	41.86	11.94	20506	<0.1059	4867
19	B	14800	8.40	10.1	238	0.4612	0.8014	27.91	15.23	23335	<0.1059	5022
19	C	14940	7.28	11.1	415	0.3787	0.7517	39.68	12.64	20871	<0.1059	4826
20	A	16730	18.08	9.88	140	0.283	0.8005	56.16	26.09	23772	<0.1059	7054
20	B	16360	15.11	7.41	130	0.2691	0.7405	53.21	24.67	21473	<0.1059	6618
20	C	17630	16.04	7.58	125	0.2541	0.8028	63.19	23.72	22476	<0.1059	7456
21	A	15613	9.92	7.47	152	0.3015	0.6975	34.78	23.35	20505	<0.1059	5599
21	B	13256	13.02	8.80	146	0.2937	0.6954	32.82	24.14	24198	<0.1059	4038
21	C	18246	12.96	7.74	181	0.3726	0.7641	33.89	34.17	22881	<0.1059	5426

Appendix H, cont.

Site	Rep.	Mn	Mo	Ni	Pb	V	Zn
09	A	1594	<5.31	58.10	13.08	41.64	77.19
09	B	1591	<5.31	63.81	12.92	44.68	83.95
09	C	1623	<5.31	58.55	12.26	42.34	78.15
10	A	498.8	<5.31	19.61	10.95	44.01	60.05
10	B	267.1	<5.31	14.25	8.759	33.26	41.69
10	C	443.6	<5.31	21.90	12.58	46.35	63.56
12	A	695.4	<5.31	31.22	14.68	45.50	82.34
12	B	587.7	<5.31	31.12	14.80	46.40	82.22
12	C	582.6	<5.31	30.42	13.22	44.05	80.36
15	A	478.8	<5.31	26.88	13.34	46.53	79.52
15	B	427.7	<5.31	27.21	14.71	44.93	79.80
15	C	515.0	<5.31	28.88	16.33	46.64	84.02
16	A	376.2	<5.31	21.46	15.50	40.44	68.52
16	B	299.6	<5.31	19.41	13.45	34.60	64.96
16	C	435.3	<5.31	12.05	12.76	27.75	50.06
17	A	447.6	<5.31	23.68	13.19	40.57	70.28
17	B	478.1	<5.31	23.87	13.84	42.29	71.10
17	C	423.1	<5.31	23.59	12.59	40.03	76.19
18	A	368.2	<5.31	30.32	16.28	49.20	92.67
18	B	363.6	<5.31	31.09	17.05	50.98	95.17
18	C	358.0	<5.31	29.17	16.28	47.61	90.74
19	A	343.8	<5.31	19.96	9.858	30.47	58.36
19	B	510.1	<5.31	22.11	14.72	38.42	72.77
19	C	402.3	<5.31	20.92	11.85	37.42	61.6
20	A	542.5	<5.31	34.38	20.48	37.66	112.0
20	B	442.6	<5.31	33.65	20.97	35.68	108.0
20	C	440.2	<5.31	37.98	20.04	37.81	111.8
21	A	393.0	<5.31	28.92	20.03	32.37	105.0
21	B	279.1	<5.31	23.40	16.52	29.75	89.70
21	C	371.9	<5.31	28.87	21.90	36.90	118.2

Appendix H, cont.

Site	Rep.	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
22	A	19910	13.89	22.3	283	0.4048	0.8478	34.10	30.56	34003	<0.1059	5800
22	B	19935	13.14	12.9	293	0.4291	0.89	35.09	33.29	31390	<0.1059	5916
22	C	14806	14.99	23.6	213	0.2877	0.7977	35.75	19.06	34359	<0.1059	5000
23	A	15184	8.13	12.9	191	0.3104	0.5211	29.71	24.33	20386	<0.1059	5070
23	B	15298	11.36	12.9	217	0.3199	0.7446	29.78	24.12	22794	<0.1059	4869
23	C	14012	8.33	11.2	145	0.2406	0.6306	51.02	18.25	24090	<0.1059	5462
24	A	19141	35.29	13.9	139	0.3958	1.006	53.58	27.07	25721	<0.1059	6229
24	B	15953	16.38	11.2	130	0.3003	0.6067	40.26	19.28	20786	<0.1059	5580
24	C	21699	27.78	15.3	152	0.4067	0.8117	62.50	27.16	26001	<0.1059	7082
25	A	11264	40.70	10.6	77.2	0.0838	0.4359	53.11	10.12	16380	<0.1059	5099
25	B	17011	35.19	12.7	136	0.3124	0.7393	50.10	21.13	21823	<0.1059	6130
25	C	16734	24.91	11.5	131	0.2551	0.6371	51.03	16.59	19134	<0.1059	6465
26	A	13256	21.09	14.6	206	0.309	0.8616	30.00	16.32	30321	<0.1059	4129
26	B	23060	14.46	18.3	316	0.4404	1.203	39.78	31.48	35590	<0.1059	6936
26	C	21598	11.97	16.3	300	0.4128	1.103	37.91	29.79	31638	<0.1059	6783
27	A	19116	9.97	19.1	287	0.5496	1.168	55.29	24.43	32674	0.1608	8219
27	B	15272	10.25	16.6	237	0.5003	0.5175	54.44	19.73	28291	0.1336	8197
27	C	14605	8.86	15.6	197	0.4937	0.4747	68.04	17.69	27308	0.1171	8228
28	A	18082	5.52	13.0	322	0.3979	0.5103	30.19	27.27	24976	<0.1059	5771
28	B	19305	5.60	14.1	333	0.4027	0.505	31.63	27.13	24403	<0.1059	6072
28	C	17440	5.91	15.4	325	0.4045	0.4432	30.98	26.75	22881	<0.1059	5983
29	A	14995	13.74	19.3	237	0.426	0.4979	43.83	20.44	29144	0.1417	6732
29	B	17175	14.46	20.8	246	0.4221	0.5402	43.17	19.74	32448	0.1334	6920
29	C	16066	12.86	19.6	214	0.3725	0.4477	41.85	16.69	31303	0.1075	6865
30	A	18007	7.21	16.1	297	0.471	0.4647	35.47	17.14	26660	<0.1059	4500
30	B	12903	7.56	16.1	291	0.4042	0.4079	34.22	11.94	22676	<0.1059	3427
30	C	17402	7.15	18.7	281	0.4561	0.552	31.18	15.96	27373	<0.1059	4612
31	A	17226	6.10	17.5	233	0.4987	0.5374	28.74	14.23	25040	<0.1059	4694
31	B	17553	7.49	17.6	232	0.4848	0.5188	26.16	13.66	27524	<0.1059	4483
31	C	17982	7.52	15.8	238	0.4974	0.6019	28.34	14.62	27740	<0.1059	4836
32	A	18738	11.82	16.7	269	0.4005	0.8385	31.68	26.87	28064	<0.1059	5562
32	B	18082	9.95	15.3	240	0.3565	0.7051	30.79	22.35	24630	<0.1059	5550
32	C	18158	10.28	16.2	268	0.3939	0.8266	32.74	26.10	25872	<0.1059	5815

Appendix H, cont.

Site	Rep.	Mn	Mo	Ni	Pb	V	Zn
22	A	369.3	<5.31	28.95	17.13	44.04	94.70
22	B	395.8	<5.31	30.29	18.62	45.11	96.71
22	C	630.6	<5.31	22.45	14.97	33.52	75.09
23	A	357.4	<5.31	24.34	15.90	32.60	81.69
23	B	815.6	<5.31	24.32	15.84	33.67	82.02
23	C	927.5	<5.31	28.11	13.57	25.15	81.94
24	A	397.4	<5.31	29.75	23.93	48.72	98.25
24	B	266.1	<5.31	24.50	18.80	39.27	73.36
24	C	395.2	<5.31	35.08	22.90	53.09	93.75
25	A	283.0	<5.31	27.07	26.27	27.00	69.15
25	B	281.6	<5.31	30.62	29.51	39.25	86.73
25	C	237.7	<5.31	31.93	31.81	36.65	80.64
26	A	357.1	<5.31	20.23	13.08	32.69	64.45
26	B	585.1	<5.31	33.68	17.99	51.61	106.8
26	C	512.0	<5.31	31.84	18.14	47.67	100.3
27	A	1330	<5.31	54.83	13.13	49.03	91.04
27	B	1377	<5.31	56.79	8.173	42.50	78.81
27	C	464.1	<5.31	52.64	7.67	40.94	69.14
28	A	296.2	<5.31	25.60	13.08	51.99	67.64
28	B	283.4	<5.31	27.10	12.87	55.76	69.37
28	C	295.7	<5.31	26.50	13.43	53.26	68.19
29	A	484.3	<5.31	40.77	8.838	43.58	80.02
29	B	548.7	<5.31	40.60	8.645	43.66	82.75
29	C	485.0	<5.31	39.63	7.012	39.27	79.56
30	A	312.6	<5.31	20.25	10.65	38.44	82.48
30	B	228.4	<5.31	15.86	9.873	31.64	57.58
30	C	300.3	<5.31	20.18	11.12	39.18	74.77
31	A	367.9	<5.31	20.18	12.29	39.03	74.05
31	B	359.6	<5.31	19.10	9.758	37.48	70.25
31	C	393.5	<5.31	20.65	10.72	39.76	74.91
32	A	439.3	<5.31	28.93	12.88	47.50	82.11
32	B	340.9	<5.31	27.21	12.30	43.71	78.09
32	C	451.2	<5.31	29.38	13.14	47.06	83.29

Appendix H, cont.

Site	Rep.	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe	Hg	Mg
33	A	15109	6.50	18.9	292	0.4309	0.7316	32.59	19.90	29640	0.1018	5388
33	B	13861	6.38	20.1	326	0.4408	0.7383	32.45	21.41	28809	0.1305	4958
33	C	15512	6.30	19.8	325	0.4559	0.7544	33.34	21.50	29370	0.103	5473
34	A	13861	8.89	16.6	190	0.3732	0.6496	30.28	18.36	26314	0.1926	4929
34	B	13344	7.53	15.3	194	0.3615	0.6328	29.73	18.08	24889	0.192	5185
34	C	12478	8.76	17.0	194	0.3767	0.6971	28.71	18.75	25915	0.1965	4808
35	A	16142	6.02	16.5	303	0.4365	0.9144	32.94	24.49	25235	<0.1059	6680
35	B	16898	4.70	16.6	296	0.4183	0.891	32.43	23.32	25991	<0.1059	6490
5	C	16218	5.50	16.5	328	0.4537	0.6907	31.13	25.91	26682	<0.1059	6167

Site	Rep.	Mn	Mo	Ni	Pb	V	Zn
33	A	646.9	<5.31	44.47	9.01	37.83	80.47
33	B	781.3	<5.31	41.10	10.43	37.66	78.22
33	C	714.2	<5.31	44.43	10.64	39.31	82.99
34	A	790.8	<5.31	36.83	10.35	39.71	79.62
34	B	817.8	<5.31	35.53	9.21	37.10	78.96
34	C	1016	<5.31	36.26	10.99	38.49	78.99
35	A	459.6	<5.31	29.52	11.46	40.94	89.67
35	B	519.0	<5.31	28.52	10.67	39.62	87.89
35	C	573.5	<5.31	29.03	11.57	41.23	86.67

APPENDIX I: GRAIN SIZE (PERCENT) AND METALS CONCENTRATIONS (MG/KG DRY WEIGHT) IN STREAM SEDIMENT FROM INNOKO NATIONAL WILDLIFE REFUGE AND FROM THE UPPER LITTLE MUD RIVER DRAINAGE, ALASKA, 1997.

Site	Clay	Sand	Silt	Al	As	Ba	Be	Ca	Cd	Cu	Fe
IN091ASW	9	52	39	12700	11.7	256	<0.688	4880	0.267	24.9	27100
IN091BSW	6	78	16	11300	14.4	229	<0.688	4150	0.308	24.0	28500
IN091CSW	18	28	54	17300	16.3	351	1.05	6850	0.446	31.1	32400
IN101ASW	10	35	55	11500	7.68	214	<0.688	5740	0.241	24.8	27900
IN101BSW	12	27	62	14800	7.37	215	1.14	6100	0.210	21.7	29600
IN101CSW	9	36	55	16800	7.90	224	1.68	6350	0.249	26.7	29900
IN121ASW	17	56	27	9890	6.24	375	<0.688	3780	0.308	23.9	114000
IN121BSW	13	57	30	13100	18.0	291	1.61	3880	0.265	24.4	79700
IN121CSW	8	60	31	17100	18.6	283	<0.688	5460	0.366	32.2	36200
IN151ASW	4	80	16	13100	15.2	313	<0.688	3630	0.315	20.5	58100
IN151BSW	7	68	26	11300	23.8	318	1.12	3450	0.330	21.1	92400
IN151CSW	6	71	23	12000	12.7	274	0.703	4010	0.277	19.2	35500
IN161ASW	8	48	44	16300	10.2	206	<0.688	5590	0.349	24.2	38600
IN161BSW	4	67	29	13400	10.3	202	<0.688	4720	0.314	23.3	30900
IN161CSW	9	41	51	12100	10.4	214	<0.688	4180	0.333	24.7	30800
IN171ASW	15	16	69	13700	10.0	186	1.4	5010	0.276	17.3	23900
IN171BSW	9	18	73	17500	11.9	229	<0.688	5820	0.348	21.5	26700
IN171CSW	10	25	65	13000	12.3	194	1.35	4520	0.308	17.2	24500
IN181ASW	14	10	76	14200	7.16	202	1.68	3710	0.364	22.0	23600
IN181BSW	13	10	77	19300	10.1	219	1.18	4420	0.387	24.9	29300
IN181CSW	13	8	79	13300	6.33	197	1.03	3450	0.376	22.1	22400
IN191ASW	11	25	65	18500	11.3	215	<0.688	4960	0.248	20.3	27300
IN191BSW	17	21	62	15900	13.6	213	1.50	4390	0.289	21.3	27700
IN191CSW	14	25	61	14100	10.2	178	<0.688	3860	0.269	17.7	24700

Appendix I, cont.

Site	Hg	Mg	Mn	Mo	Na	Ni	Pb	S	Se	Sr	Zn
IN091ASW	0.1190	6750	1100	<0.625	190	56.9	7.72	361	0.527	30.6	77.3
IN091BSW	0.0895	7660	1750	<0.625	228	65.6	7.08	297	0.529	24.1	79.2
IN091CSW	0.2080	5710	1990	<0.625	265	53.2	10.1	671	1.20	39.8	87.8
IN101ASW	0.0814	4430	709	<0.625	180	17.4	7.59	395	0.279	32.6	65.0
IN101BSW	0.0620	5050	530	<0.625	219	18.6	7.56	343	0.286	33.6	70.2
IN101CSW	0.1380	5470	644	<0.625	231	21.2	7.93	457	0.404	35.0	74.0
IN121ASW	0.1070	3610	1180	1.87	163	19.9	6.59	738	0.740	31.4	61.5
IN121BSW	0.1030	4360	1250	0.960	193	22.9	7.53	512	0.627	27.6	75.9
IN121CSW	0.1350	5440	1870	<0.625	241	27.6	9.66	483	0.750	35.5	91.8
IN151ASW	0.0560	3840	899	<0.625	146	20.3	7.95	422	0.342	27.3	70.0
IN151BSW	0.0559	3230	578	<0.625	127	17.6	7.64	505	0.377	27.8	60.7
IN151CSW	0.0466	3820	1550	<0.625	158	19.1	8.04	319	0.253	24.5	69.0
IN161ASW	0.0760	3820	1310	<0.625	171	19.4	8.56	375	0.419	26.0	99.4
IN161BSW	0.0677	3850	1030	<0.625	261	20.4	8.21	369	0.399	29.8	78.3
IN161CSW	0.0747	3830	1050	<0.625	200	20.0	8.20	395	0.438	26.7	76.9
IN171ASW	0.0824	3610	957	<0.625	260	17.4	8.97	325	0.311	27.1	67.9
IN171BSW	0.1030	4260	979	<0.625	314	20.7	9.81	431	0.509	34.2	78.0
IN171CSW	0.1120	3280	808	0.627	254	25.9	9.63	360	0.375	26.4	68.1
IN181ASW	0.0514	4270	562	<0.625	203	20.4	9.49	335	0.270	21.4	76.5
IN181BSW	0.0621	4600	398	<0.625	274	22.5	10.1	403	0.403	25.8	86.2
IN181CSW	0.0518	4110	497	<0.625	193	19.6	9.35	315	0.359	20.1	73.5
IN191ASW	0.0804	4860	429	<0.625	375	22.1	8.35	253	0.370	28.3	84.8
IN191BSW	0.0856	4650	482	<0.625	261	21.4	8.91	316	0.346	26.4	82.7
IN191CSW	0.0815	3840	400	<0.625	214	18.7	8.58	300	0.307	22.5	78.2

Appendix I, cont.

Site	Clay	Sand	Silt	Al	As	Ba	Be	Ca	Cd	Cu	Fe
IN261ASW	10	56	34	13000	28.7	182	<0.688	2990	0.227	17.3	45800
IN261BSW	11	67	22	10200	30.5	178	0.832	2440	0.244	16.3	58800
IN261CSW	9	63	28	11700	27.6	164	<0.688	3010	0.226	14.9	46300
IN271ASW	47	27	26	8850	29.1	338	<0.688	3890	0.348	18.7	161000
IN271BSW	39	42	19	7290	49.7	261	<0.688	3560	0.318	15.5	166000
IN271CSW	18	51	31	14000	19.8	241	<0.688	3900	0.245	21.1	81500
IN281ASW	14	9	78	20300	9.41	298	<0.688	5490	0.274	28.9	31500
IN281BSW	15	8	77	16300	7.76	258	0.936	4630	0.255	24.8	27500
IN281CSW	13	9	79	18900	8.82	292	<0.688	5140	0.270	28.6	30400
IN291ASW	20	12	68	22500	17.9	312	0.996	4550	0.261	23.4	35800
IN291BSW	21	12	67	20200	19.4	311	1.41	4820	0.263	24.6	36100
IN291CSW	16	14	70	20100	18.3	309	<0.688	4730	0.260	24.6	35000
IN301ASW	11	47	42	19500	10.6	256	2.28	4030	0.235	18.7	27600
IN301BSW	18	9	73	20200	10.1	270	<0.688	4170	0.267	20.7	28000
IN301CSW	16	11	73	22900	10.7	276	<0.688	4440	0.275	20.9	28700
IN311ASW	18	14	68	17600	13.8	227	0.892	4380	0.221	15.2	28600
IN311BSW	15	14	70	17800	15.7	226	1.28	4650	0.257	15.7	27900
IN311CSW	12	16	72	13000	16.2	211	1.89	4310	0.237	14.1	27500
IN321ASW	20	5	75	21200	12.0	287	<0.688	4710	0.388	32.6	30500
IN321BSW	18	5	77	25100	12.6	296	1.36	5160	0.345	30.5	31700
IN321CSW	19	5	76	22800	12.6	296	<0.688	4850	0.357	32.9	31200
IN331ASW	9	54	36	12500	7.0	250	1.24	3040	0.198	17.5	25600
IN331BSW	9	53	38	13600	7.29	253	<0.688	3170	0.211	18.0	26300
IN331CSW	9	52	39	16300	6.55	276	1.54	3200	0.189	17.7	25700
IN341ASW	10	30	60	13200	12.5	201	<0.688	3130	0.225	18.8	46700
IN341BSW	8	37	55	14600	14.4	235	0.701	3790	0.240	24.2	41800
IN341CSW	10	40	51	14000	14.4	223	0.722	2800	0.180	19.4	50100
IN351ASW	17	8	75	16500	4.46	240	<0.688	5200	0.282	17.8	25000
IN351BSW	13	8	79	14300	5.71	225	<0.688	4940	0.285	16.3	25400
IN351CSW	17	6	77	17400	6.12	261	3.27	5300	0.296	18.2	26400

Appendix I, cont.

Site	Hg	Mg	Mn	Mo	Na	Ni	Pb	S	Se	Sr	Zn
IN261ASW	0.0446	3640	477	<0.625	151	18.2	16.6	407	0.338	17.3	64.6
IN261BSW	0.0442	2970	353	<0.625	115	14.9	7.77	417	0.245	15.6	56.9
IN261CSW	0.0372	3360	455	<0.625	104	16.5	7.97	339	0.265	16.8	59.9
IN271ASW	0.1120	3410	859	1.91	140	31.3	5.30	794	0.632	41.5	60.2
IN271BSW	0.0939	2800	685	1.51	128	24.2	4.43	792	0.593	36.6	48.9
IN271CSW	0.1460	5830	600	1.03	202	43.1	7.10	483	0.542	29.6	83.6
IN281ASW	0.0680	5350	513	<0.625	241	25.3	9.97	392	0.454	37.6	81.1
IN281BSW	0.0662	4750	544	<0.625	232	22.2	8.84	331	0.350	31.3	72.3
IN281CSW	0.0525	5480	512	<0.625	233	25.3	10.1	369	0.365	36.1	80.8
IN291ASW	0.1660	5300	880	<0.625	237	30.2	10.6	440	0.550	37.4	89.0
IN291BSW	0.1720	5340	932	<0.625	221	29.9	11.0	447	0.503	38.9	87.1
IN291CSW	0.1680	5360	867	<0.625	203	30.2	10.7	446	0.532	38.2	85.6
IN301ASW	0.0595	4040	637	<0.625	262	17.6	9.33	367	0.255	30.3	77.4
IN301BSW	0.0625	4620	686	<0.625	240	19.6	10.3	364	0.319	30.5	83.1
IN301CSW	0.0613	4790	634	<0.625	277	20.3	10.7	378	0.344	32.6	84.7
IN311ASW	0.0769	4090	697	<0.625	278	16.7	8.53	353	0.220	42.1	70.5
IN311BSW	0.0627	4230	677	<0.625	309	17.2	8.85	367	0.257	42.3	72.7
IN311CSW	0.0558	3640	792	<0.625	248	14.6	8.26	357	0.309	41.1	65.0
IN321ASW	0.0825	5390	587	<0.625	205	26.9	11.7	454	0.599	26.9	92.6
IN321BSW	0.0688	5450	628	<0.625	258	27.0	11.5	422	0.597	30.2	94.5
IN321CSW	0.0746	5630	525	<0.625	214	27.8	11.9	449	0.660	28.4	94.0
IN331ASW	0.0723	4150	884	<0.625	126	34.2	6.75	249	0.362	30.4	73.0
IN331BSW	0.0784	4160	907	<0.625	144	34.4	6.99	274	0.424	31.3	73.4
IN331CSW	0.0702	4510	830	<0.625	183	34.3	6.99	269	0.386	32.7	74.6
IN341ASW	0.1970	3980	697	<0.625	179	27.2	7.37	381	0.378	23.5	76.4
IN341BSW	0.2230	4650	1490	<0.625	201	32.7	8.18	487	0.483	30.6	83.5
IN341CSW	0.3320	4090	480	<0.625	185	28.0	6.88	355	0.381	22.7	76.8
IN351ASW	0.0478	5410	307	<0.625	368	21.7	6.55	346	0.171	34.5	91.5
IN351BSW	0.0428	4990	367	<0.625	259	20.2	6.40	325	0.178	31.4	87.2
IN351CSW	0.0430	5540	484	<0.625	333	22.4	6.99	369	0.197	36.4	94.5

APPENDIX J: RESULTS OF STATISTICAL ANALYSES

1. Significant results of tests for differences in metal concentrations in water between sets of sites sampled before and after a rain event in 1996, and the same sets of sites sampled in 1997 with no rain event (multivariate ANOVAs or Mann-Whitney U-tests, = 0.05).

Data Set, Year	Year	Multivariate Statistics	Response Variables	Univariate Statistics
Total Metals	1996	Wilks = 0.01	Aluminum	$F_{1,82} = 128$, $P < 0.001$
		$F_{6,77} = 1258$	Barium	$F_{1,82} = 39.4$, $P < 0.001$
		$P < 0.001$	Iron	$F_{1,82} = 22.5$, $P < 0.001$
			Manganese	$F_{1,82} = 39.7$, $P < 0.001$
Total Metals	1996[a]		Chromium	$U = 159$, $P < 0.001$
			Nickel	$U = 152$, $P < 0.001$
			Vanadium	$U = 28.0$, $P < 0.001$
			Zinc	$U = 84.5$, $P < 0.001$
Total Metals	1997	Wilks = 0.67	Aluminum	$F_{1,54} = 9.45$, $P = 0.008$
		$F_{9,46} = 2.50$	Arsenic	$F_{1,54} = 8.24$, $P = 0.006$
		$P = 0.020$	Nickel	$F_{1,54} = 4.3$, $P = 0.043$
Dissolved Metals	1996	Wilks = 0.51	Aluminum	$F_{1,42} = 15.4$, $P < 0.001$
		$F_{6,77} = 5.9$	Magnesium	$F_{1,42} = 15.4$, $P < 0.001$
		$P < 0.001$		
Dissolved Metals	1997	Wilks = 0.63	Arsenic	$F_{1,51} = 8.40$, $P = 0.006$
		$F_{8,44} = 3.30$	Iron	$F_{1,51} = 5.50$, $P = 0.023$
		$P = 0.005$	Nickel	$F_{1,51} = 4.18$, $P = 0.046$

[a] Mann-Whitney U-tests.

2. Significant results of tests for differences in metal concentrations between kidney, liver, and muscle (multivariate ANOVAs).

Data Set, Year	Year	Multivariate Statistics	Response Variables	Univariate Statistics
Northern Pike, Kidney, Liver, Muscle	1996	Wilks < 0.001	Arsenic	$F_{2,15} = 11$, $P = 0.001$
		$F_{10,22} = 78$	Barium	$F_{2,15} = 14$, $P < 0.001$
		$P < 0.001$	Cadmium	$F_{2,15} = 11$, $P < 0.001$
			Copper	$F_{2,15} = 48$, $P < 0.001$
			Iron	$F_{2,15} = 160$, $P < 0.001$
			Mercury	$F_{2,15} = 3.0$, $P = 0.08$
			Magnesium	$F_{2,15} = 61$, $P < 0.001$
			Manganese	$F_{2,15} = 4.5$, $P = 0.03$
			Nickel	$F_{2,15} = 12$, $P = 0.001$
			Selenium	$F_{2,15} = 167$, $P < 0.001$
			Strontium	$F_{2,15} = 11$, $P = 0.001$
			Zinc	$F_{2,15} = 208$, $P < 0.001$
Arctic Grayling, Kidney, Liver, Muscle	1996	Wilks < 0.001	Arsenic	$F_{2,12} = 1.5$, $P = 0.27$
		$F_{4,22} = 33$	Barium	$F_{2,12} = 9.7$, $P = 0.003$
		$P = 0.002$	Copper	$F_{2,12} = 8.6$, $P = 0.005$
			Iron	$F_{2,12} = 116$, $P < 0.001$
			Mercury	$F_{2,12} = 3.5$, $P = 0.06$
			Magnesium	$F_{2,12} = 9.9$, $P = 0.003$
			Manganese	$F_{2,12} = 15$, $P < 0.001$
			Nickel	$F_{2,12} = 20$, $P < 0.001$
			Selenium	$F_{2,12} = 184$, $P < 0.001$
			Strontium	$F_{2,12} = 6.8$, $P = 0.011$
			Zinc	$F_{2,12} = 1027$, $P < 0.001$
Northern Pike, Kidney, Liver, Muscle	1997	Wilks = 0.007	Arsenic	$F_{1,19} = 1.4$, $P = 0.25$
		$F_{8,12} = 223$	Copper	$F_{1,19} = 40$, $P < 0.001$
		$P < 0.001$	Iron	$F_{1,19} = 320$, $P < 0.001$
			Mercury	$F_{1,19} = 1.5$, $P = 0.24$
			Magnesium	$F_{1,19} = 204$, $P < 0.001$
			Selenium	$F_{1,19} = 303$, $P < 0.001$
			Strontium	$F_{1,19} = 0.47$, $P < 0.5$
			Zinc	$F_{1,19} = 1234$, $P < 0.001$
Arctic Grayling, Kidney, Liver, Muscle	1997	Wilks = 0.002	Arsenic	$F_{1,12} = 4.0$, $P = 0.07$
		$F_{5,8} = 282$	Copper	$F_{1,12} = 4.7$, $P = 0.05$
		$P < 0.001$	Iron	$F_{1,12} = 204$, $P<0.001$
			Mercury	$F_{1,12} = 5.4$, $P = 0.038$
			Magnesium	$F_{1,12} = 73$, $P < 0.001$
			Selenium	$F_{1,12} = 684$, $P<0.001$
			Strontium	$F_{1,12} = 13$, $P = 0.004$
			Zinc	$F_{1,12} = 234$, $P < 0.001$

APPENDIX K: METALS CONCENTRATIONS (MG/KG DRY WEIGHT) IN KIDNEY, LIVER, MUSCLE AND WHOLE BODY SAMPLES OF ARCTIC GRAYLING (*THYMALLUS ARCTICUS*), NORTHERN PIKE (*ESOX LUCIUS*), CHINOOK SALMON (*ONCORYNCHUS TSHAWYTSCHA*), SILVER SALMON (*O. KISUTCH*), AND SLIMY SCULPIN (*COTTUS COGNATUS*) FROM INNOKO NATIONAL WILDLIFE REFUGE, ALASKA, 1996.

Site	Rep.	Species[1]	Tissue[2]	As	B	Ba	Be	Cd	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
9	A	AG	K	0.3	<3	1	<0.02	0.72	<4	720	0.43	757	3.4	<1	0.73	<0.03	20	1.4	10	81.3
9	B	AG	K	0.4	<3	2	<0.02	0.69	7	360	0.5	910	3.1	<1	0.3	<0.03	13	1.6	5	85.7
9	C	AG	K	<0.3	<3	0.78	<0.02	0.35	4.9	686	0.4	787	4.6	<1	0.3	<0.03	15	3.3	5.3	79.3
9	D	AG	K	0.4	<3	1	<0.02	0.36	4	759	0.69	618	2	<1	0.88	0.14	13	1.4	5	82.5
9	E	AG	K	0.6	<3	0.4	<0.02	0.52	4	1000	0.84	756	2.1	<1	1.1	0.04	19	0.88	8.6	87
19	A	NP	K	0.4	<3	4.9	<0.02	0.92	4.2	522	1.1	744	3.3	<1	0.97	<0.03	6.5	2.4	7.5	746
27[3]	A	NP	K	<0.7	<8	<1	<.06	<0.3	<10	620	0.38	1060	2	<3	<0.3	<.07	5.2	2	<10	282
35	A	NP	K	<0.3	<3	0.9	<0.02	0.38	<4	350	0.2	868	3.3	<1	0.57	<0.03	4.4	3.4	<4	778
36	A	NP	K	0.2	<3	1.6	<0.02	0.2	7.7	749	2.7	701	3.5	<1	0.28	0.04	6.1	0.73	<4	940
36	B	NP	K	<0.3	<3	0.72	<0.02	0.42	4.8	683	1.7	768	2.5	<1	0.1	0.13	4.8	0.9	<4	574
36	C	NP	K	0.4	<3	0.9	<0.02	0.45	7	357	0.31	838	3.4	<1	0.2	<0.03	6.1	0.6	<4	448
36	D	NP	K	0.2	<3	1.4	<0.02	0.3	5.9	470	2.4	772	3.3	<1	0.4	0.05	5.5	0.86	<4	692
36	E	NP	K	<0.3	<3	0.8	<0.02	0.2	4	396	0.54	772	2.4	<1	0.2	<0.03	5.5	1.1	<4	921
36	F	NP	K	<0.3	<3	1.3	<0.02	0.35	4	479	2.6	690	2.5	<1	0.2	<0.03	6.8	2.8	<4	906
9	A	AG	L	0.5	<0.5	0.34	<0.02	0.3	4.4	226	0.3	759	10	<0.3	0.2	<0.04	8.5	0.89	0.8	69.6
9	B	AG	L	0.4	<0.5	0.1	<0.02	0.3	4.9	103	0.31	649	6.7	<0.3	0.2	<0.04	6.6	0.35	<0.7	67.1
9	C	AG	L	0.6	<0.5	0.09	<0.02	0.2	5.1	121	0.27	734	8.5	<0.3	0.75	<0.04	6.3	0.38	<0.7	75.7
9	D	AG	L	0.4	<0.5	0.09	<0.02	0.23	3.9	226	0.42	728	6.9	0.4	0.12	<0.04	6.8	0.53	<0.7	82.4
9	E	AG	L	<0.4	<0.5	<0.06	<0.02	0.2	4.2	368	0.5	619	4.5	<0.3	0.16	<0.04	10	0.29	<0.7	67.4
19	A	NP	L	0.2	<0.5	0.1	<0.02	0.28	35	2920	0.615	458	4	0.4	0.16	<0.04	4	0.1	6.5	110
27[3]	A	NP	L	<0.5	<0.6	<0.06	<0.02	<0.1	9.6	157	0.21	630	4.2	<0.3	0.48	<0.04	4.1	0.26	<0.8	163
35	A	NP	L	<0.4	<0.5	<0.06	<0.02	<0.1	13	300	0.071	440	2.2	<0.3	0.3	<0.04	3.5	0.09	<0.7	76.6
36	A	NP	L	<0.4	<0.5	<0.06	<0.02	0.092	44	749	1.5	373	2.2	<0.3	0.2	<0.04	6.2	0.09	<0.7	125
36	B	NP	L	<0.4	<0.5	<0.06	<0.02	0.09	39	844	1.1	497	2.1	<0.3	0.09	<0.04	6.4	0.09	<0.7	118
36	C	NP	L	<0.4	<0.5	<0.06	<0.02	0.04	22	451	0.11	516	3.6	0.3	0.04	<0.04	3.2	0.1	<0.7	83.8
36	D	NP	L	<0.4	<0.5	<0.06	<0.02	0.03	16	157	0.55	324	1.3	<0.3	<0.09	<0.04	3.3	0.08	<0.7	73.1
36	E	NP	L	<0.4	<0.5	0.61	<0.02	<0.1	69	1030	0.45	719	5.3	0.8	0.45	<0.04	5.2	0.26	<0.7	229
36	F	NP	L	<0.4	<0.5	<0.06	<0.02	0.1	9.8	551	0.841	382	1.2	<0.3	0.09	0.07	4.3	<.07	<0.7	61.3

Appendix K, cont.

Site	Rep.	Species	Tissue	As	B	Ba	Be	Cd	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
9	A	AG	M	0.21	<0.7	0.64	<0.005	<0.03	0.9	19	0.33	1150	4.3	<0.4	0.06	<0.04	1.8	2.2	<0.5	15
9	B	AG	M	0.1	<0.7	0.1	<0.005	<0.03	0.9	8.4	0.4	1090	1.5	<0.4	0.06	<0.04	1.5	0.66	<0.5	14
9	C	AG	M	0.21	<0.7	0.07	0.006	<0.03	1	12	0.29	929	1.2	<0.4	0.09	<0.04	1.2	0.82	<0.5	15
9	D	AG	M	0.1	<0.7	<0.06	0.008	<0.03	0.8	14	0.39	810	0.93	<0.4	0.05	<0.04	1	0.36	<0.5	13
9	E	AG	M	0.26	<0.7	0.1	<0.005	<0.03	1	17	0.58	935	1.3	<0.4	0.07	<0.04	1.3	0.93	<0.5	13
19	A	NP	M	0.93	<0.7	1.3	<0.005	<0.03	<0.6	13	2.2	1370	2.9	<0.4	<0.04	<0.04	0.6	2.92	<0.5	14
27	A	NP	M	0.3	<0.7	0.3	<0.005	<0.03	<0.6	10	0.75	1430	1.3	<0.4	<0.04	<0.04	0.96	1.7	<0.5	20
35	A	NP	M	0.59	<0.7	0.44	<0.005	<0.03	<0.6	7.6	0.29	1410	1.4	<0.4	0.09	<0.04	0.78	1.9	<0.5	15
36	A	NP	M	0.21	<0.7	0.07	<0.005	<0.03	1	13	3.52	1270	0.58	<0.4	<0.04	<0.04	0.65	0.19	<0.5	16
36	B	NP	M	0.29	<0.7	0.08	<0.005	<0.03	<0.6	6.4	2.4	1360	0.54	<0.4	0.05	<0.04	0.73	0.23	<0.5	17
36	C	NP	M	0.27	<0.7	0.29	0.01	<0.03	<0.6	6.6	0.61	1450	1.6	<0.4	0.05	<0.04	0.63	1.4	<0.5	14
36	D	NP	M	0.37	<0.7	0.09	<0.005	<0.03	0.6	4.7	2.6	1390	0.55	<0.4	0.05	<0.04	0.5	0.32	<0.5	13
36	E	NP	M	0.33	<0.7	1.1	<0.005	<0.03	0.7	10	1.2	1400	3.4	<0.4	<0.04	<0.04	0.77	5.25	<0.5	14
36	F	NP	M	0.31	<0.7	0.66	<0.005	<0.03	<0.6	6.3	2.8	1420	2	<0.4	<0.04	<0.04	0.4	5.03	<0.5	14

Appendix K, cont.

Site	Rep.	Species	Tissue	As	B	Ba	Be	Cd	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
20	A	CS	W	0.4	3	2.3	<0.01	0.07	2.8	75	0.19	1210	3.8	<0.4	0.56	0.20	1.5	19	<0.9	167
20	B	CS	W-C	0.61	5.1	3.7	<0.01	0.06	3	108	0.15	1310	6.8	<0.4	0.27	0.14	1.2	23	<0.9	138
20	C	CS	W-C	0.64	4.2	2.5	<0.01	0.04	3.3	77.6	0.14	1170	4.8	<0.4	0.14	0.22	1.3	15	<0.9	110
20	D	CS	W-C	0.7	6	4.3	<0.01	<0.06	2.7	87.1	0.17	1280	7.4	<0.4	0.31	0.28	1.1	22	<0.9	147
20	E	CS	W-C	0.5	7.5	3	<0.01	0.08	3.3	96.7	0.13	1250	7.1	<0.4	0.16	0.18	1.1	18	<0.9	122
20	F	CS	W-C	0.5	7.6	3.9	<0.01	0.05	2.6	95.5	0.15	1270	6.1	<0.4	0.19	0.21	1.2	19	<0.9	127
20	G	CS	W	0.4	8.1	3.3	<0.01	0.04	3.1	89.2	0.19	1250	4.9	<0.4	0.16	0.09	0.92	16	<0.9	143
20	H	CS	W-C	0.5	8.2	2.8	<0.01	<0.06	2.4	79.6	0.15	1270	5.9	<0.4	0.1	0.08	1.2	17	<0.9	121
20	I	CS	W-C	0.4	8.1	4.4	<0.01	0.07	4.2	104	0.15	1270	6.8	<0.4	0.17	0.17	1.1	22	<0.9	139
20	J	CS	W	0.66	9	3.5	<0.01	0.08	321	141	0.14	1230	12	<0.4	2.6	0.76	1.4	16	<0.9	123
20	K	CS	W-C	0.6	9.9	3.3	<0.01	0.03	2.1	69.8	0.14	1280	6.3	<0.4	0.15	0.18	0.97	20	<0.9	119
20	L	CS	W-C	0.5	<1	2.9	<0.01	0.07	3.1	84.4	0.14	1270	7.3	<0.4	0.18	0.07	1.3	22	<0.9	129
20	M	CS	W-C	0.3	<1	2.5	<0.01	0.05	2.4	74.6	0.14	1260	5.6	<0.4	0.2	0.13	0.93	17	<0.9	116
20	N	CS	W-C	0.5	4.5	3.1	<0.01	0.04	2.7	76.1	0.15	1230	7.7	0.4	0.18	0.17	0.81	17	<0.9	125
21	A	CS	W-C	0.5	6.3	8.7	<0.01	0.11	3.3	124	0.15	1330	10	0.4	0.26	0.08	0.69	18	<0.9	151
21	B	CS	W-C	0.4	9.3	6.5	<0.01	0.07	3.3	147	0.14	1300	7.5	<0.4	0.22	0.09	1.1	16	<0.9	125
21	C	CS	W-C	0.5	10	8	<0.01	0.093	3.5	151	0.14	1340	9.4	<0.4	0.23	0.08	1.3	22	<0.9	143
21	D	CS	W-C	1	8	8.98	<0.01	0.08	3.3	190	0.16	1330	9.2	<0.4	0.33	0.10	1.1	19	<0.9	134
21	E	CS	W-C	0.5	9.5	6.7	<0.01	0.06	6.7	130	0.12	1330	8.4	<0.4	0.23	0.10	1.3	17	<0.9	124
24	A	SS	W-C	1.9	<1	2.4	<0.01	0.06	2.5	77.8	0.1	1400	7.1	0.4	0.13	0.27	0.96	13.9	<0.9	137
24	B	SS	W-C	2.6	<1	4.4	<0.01	0.2	3.3	147	0.15	1470	7.5	<0.4	0.4	0.47	0.99	14.7	<0.9	168
24	C	SS	W-C	2	<1	3.5	<0.01	0.14	3	92.6	0.15	1380	6.4	<0.4	0.26	0.41	0.88	9.71	<0.9	153
24	D	SS	W-C	3.3	<1	3.2	<0.01	0.09	2.8	110	0.16	1320	7.2	<0.4	0.27	0.25	1.3	10.1	<0.9	161
24	H	SS	W-C	0.94	<1	3.1	<0.01	0.11	4.3	91.8	0.14	1290	21.7	<0.4	0.24	0.28	1.2	12.5	<0.9	135
24	I	S	W-C	6.2	<1	10.1	<0.01	0.093	2.9	227	0.14	1740	29.3	0.4	0.51	1.4	3.8	30.2	1	114
24	K	S	W-C	13	<1	10.1	<0.01	0.16	6.1	318	0.3	1810	23.8	<0.4	0.82	0.48	2.5	32.1	2	198
24	L	S	W	3	<1	5.5	<0.01	0.13	2.4	114	0.429	1730	23.9	<0.4	0.5	0.32	3.6	28.4	<0.9	218

[1]AG =Arctic grayling, NP = northern pike, CS = chinook salmon, SS = silver salmon, and S = slimy sculpin.

[2] K = kidney, L = liver, M = muscle, W = whole body with one fish per sample, W-C = whole body with two fish per sample.

[3] Higher LODs for this sample are the result of low sample weight.

APPENDIX L: TOTAL LENGTH, FORK LENGTH, WEIGHT, AND GENDER OF FISH CAPTURED FOR TISSUE METALS ANALYSIS AT INNOKO NATIONAL WILDLIFE REFUGE, ALASKA, 1996.

Site	Rep.	Species[1]	TL[2] (mm)	FL[3] (mm)	Weight (g)	Gender	Age (yr.)
9	A	AG	325	300	292	M	5
9	B	AG	355	330	422	F	5
9	C	AG	365	340	472	F	6
9	D	AG	400	380	662	F	6
9	E	AG	450	420	772	M	6
19	A	NP	590	560	1142	M	
27	A	NP	360	340	296	M	2
35	A	NP	485	460	758	F	3
36	A	NP	480	450	704	M	2
36	B	NP	770	730	2960	F	5
36	C	NP	760	720	2444	M	4
36	D	NP	770	730	2940	F	7
36	E	NP	530	490	798	M	3
36	F	NP	900	860	>5000	F	8

[1]AG =Arctic grayling (*Thymallus arcticus*), NP = northern pike (*Esox lucius*).
[2] Total length
[3] Fork length.

APPENDIX M: METALS CONCENTRATIONS (MG/KG DRY WEIGHT) IN KIDNEY, LIVER, AND MUSCLE SAMPLES OF ARCTIC GRAYLING (*THYMALLUS ARCTICUS*) AND NORTHERN PIKE (*ESOX LUCIUS*) FROM INNOKO NATIONAL WILDLIFE REFUGE, ALASKA, 1997.

Site	Rep.	Species[1]	Tissue[2]	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe
9	A[3]	AG	K	<9	0.4	<2	0.3	<0.05	0.5	<1	3	892
9	B	AG	K	8	0.37	<1	0.3	<0.05	0.73	1	3	1030
9	C[3]	AG	K	<5	0.5	<1	0.3	0.04	0.39	<0.8	2.6	1070
9	D[3]	AG	K	<10	3.8	<3	0.3	<0.06	0.6	<2	3	792
9	E	AG	K	13	0.35	<1	0.62	0.04	0.37	<0.8	3.4	834
12	A	NP	K	29	1.5	<1	2	<0.05	0.69	1	4.9	313
16	A[3]	AG	K	10	1.4	<2	0.56	<0.05	0.59	<1	4.9	466
17	A[3]	AG	K	<10	1	<4	0.4	<0.08	1.6	<2	4	870
27	A	NP	K	78	0.43	<1	1.4	<0.05	0.65	0.8	5.1	481
28	A	NP	K	24	0.53	<1	0.49	0.04	0.2	<0.8	3.8	272
29	A[3]	NP	K	72	0.9	<2	2.2	0.09	0.92	<1	4.5	437
34	A	NP	K	13	0.53	<1	0.65	<0.05	0.62	1	3.4	450
34	B	NP	K	21	0.59	<1	0.83	<0.05	0.43	1	3.8	516
36	A	NP	K	5	0.4	<1	1.8	0.05	0.2	0.6	3	682
36	B	NP	K	54	0.61	<1	0.99	<0.05	0.29	<0.8	3.8	745
36	C	NP	K	10	0.3	<1	0.91	<0.05	0.2	0.6	3.7	420
36	D	NP	K	25	0.3	<1	0.58	<0.05	0.39	<0.8	4.3	719
36	E	NP	K	82	0.4	<1	1.4	<0.05	0.56	0.7	4.1	689

Appendix M, cont.

Site	Rep.	Species	Tissue	Al	As	B	Ba	Be	Cd	Cr	Cu	Fe
9	A[3]	AG	M	<5	0.4	<1	0.3	<0.05	<0.1	<0.8	0.9	6
9	B	AG	M	5	0.4	<1	0.2	<0.05	<0.1	1	12	33
9	C[3]	AG	M	17	0.4	<1	0.2	<0.05	<0.1	<0.8	1.5	26
9	D[3]	AG	M	<5	0.3	<1	<0.1	<0.05	<0.1	<0.8	1.5	24
9	E	AG	M	<5	0.4	<1	<0.1	0.05	<0.1	<0.8	1	15
12	A	NP	M	<5	0.5	<1	2.7	<0.05	<0.1	<0.8	<0.5	6
16	A[3]	AG	M	<5	0.4	<1	<0.1	<0.05	<0.1	<0.8	1	10
17	A[3]	AG	M	<5	0.4	<1	0.2	<0.05	<0.1	<0.8	0.7	6
27	A	NP	M	<5	0.3	<1	<0.1	0.1	0.2	1	<0.5	<4
28	A	NP	M	<5	1.1	1	<0.1	<0.05	<0.1	<0.8	0.7	<4
29	A[3]	NP	M	5	0.99	1	0.64	<0.05	<0.1	<0.8	0.7	<4
34	A	NP	M	6	0.67	1	0.54	<0.05	<0.1	<0.8	1	5
34	B	NP	M	<5	0.64	<1	0.2	<0.05	<0.1	<0.8	0.6	<4
36	A	NP	M	5	0.61	<1	<0.1	<0.05	<0.1	<0.8	0.7	<4
36	B	NP	M	<5	1.2	1	<0.1	<0.05	<0.1	<0.8	0.8	<4
36	C	NP	M	<5	0.2	1	<0.1	<0.05	<0.1	<0.8	0.7	4
36	D	NP	M	<5	0.69	<1	<0.1	<0.05	<0.1	<0.8	1	<4
36	E	NP	M	<5	0.9	<1	0.2	<0.05	<0.1	<0.8	1	<4

Appendix M, cont.

Site	Rep.	Species	Tissue	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
9	A[3]	AG	K	0.52	737	3.8	<1	2	<0.7	11	0.75	9.5	66.1
9	B	AG	K	0.65	811	4.7	<0.6	1	<0.4	11	0.91	15	62.1
9	C[3]	AG	K	0.48	773	4	<0.6	0.8	<0.5	14	0.63	12	57
9	D[3]	AG	K	0.56	718	3.1	<2	2	<1	9.6	0.71	8.1	71.4
9	E	AG	K	0.55	763	4.3	<0.6	1.7	<0.4	11	0.62	6.6	64.2
12	A	NP	K	1.1	883	3.1	<0.6	0.9	<0.4	5.8	0.8	2.1	876
16	A[3]	AG	K	0.35	947	3.2	<0.900	<1	<.6	12	0.77	5.8	77.4
17	A[3]	AG	K	0.48	774	3.8	<2	<2	1	11	0.61	9.7	83.8
27	A	NP	K	2.3	750	3	<0.6	1	<0.4	8	1.1	1.1	796
28	A	NP	K	0.29	954	2.3	<0.6	<0.6	<0.4	4.9	1.2	1.4	498
29	A[3]	NP	K	0.36	879	3.4	<1	<1	<0.6	5.7	1.8	2.1	1060
34	A	NP	K	0.31	646	2	<0.6	<0.6	<0.4	5.7	0.66	0.6	580
34	B	NP	K	0.22	837	2.1	<0.6	<0.6	<0.4	5	1.1	1	396
36	A	NP	K	2	694	4.2	<0.6	<0.6	<0.4	3.6	7.7	<0.600	830
36	B	NP	K	1.7	772	2	<0.6	<0.6	<0.4	4.8	1	0.8	974
36	C	NP	K	3.72	681	2	<0.6	<0.6	<0.4	5.4	1	1	892
36	D	NP	K	2	685	2	<0.6	<0.6	<0.4	4.2	0.8	0.7	654
36	E	NP	K	3.57	759	2	<0.6	<0.6	<0.4	5.1	1	1	1060

Appendix M, cont.

Site	Rep.	Species	Tissue	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr	V	Zn
9	A[3]	AG	M	0.42	1220	2	<0.6	<0.6	<0.4	2.2	1	<0.6	11
9	B	AG	M	0.49	1190	4	<0.6	<0.6	<0.4	2.7	1	<0.6	16
9	C[3]	AG	M	0.37	1130	2	<0.6	<0.6	<0.4	2.2	1	<0.6	14
9	D[3]	AG	M	0.46	1080	1	<0.6	<0.6	<0.4	2.3	0.7	<0.6	16
9	E	AG	M	0.43	1070	2	<0.6	<0.6	<0.4	1.9	0.9	<0.6	14
12	A	NP	M	2.25	1400	4.3	<0.6	<0.6	<0.4	1.4	6.5	<0.6	17
16	A[3]	AG	M	0.24	1070	2	<0.6	<0.6	<0.4	2.2	0.9	<0.6	22.9
17	A[3]	AG	M	0.35	1290	2	<0.6	<0.6	<0.4	1.9	1	<0.6	16
27	A	NP	M	3.34	1410	<1.00	<0.6	0.9	1.9	1.9	<0.5	<0.6	13
28	A	NP	M	0.632	1400	<1.00	<0.6	0.7	<0.4	1.1	0.7	<0.6	14
29	A[3]	NP	M	0.701	1380	<1.00	<0.6	<0.6	<0.4	1.2	2.4	<0.6	14
34	A	NP	M	0.734	1430	<1.00	<0.6	<0.6	<0.4	1.5	2.6	<0.6	17
34	B	NP	M	0.549	1420	<1.00	<0.6	<0.6	<0.4	1.7	1	<0.6	14
36	A	NP	M	3.1	1370	<1.00	<0.6	<0.6	<0.4	0.99	0.7	<0.6	15
36	B	NP	M	2.8	1320	<1.00	<0.6	<0.6	0.4	1.1	1	<0.6	16
36	C	NP	M	5.8	1350	<1.00	<0.6	<0.6	<0.4	1	<0.5	<0.6	21
36	D	NP	M	3.44	1360	<1.00	<0.6	<0.6	<0.4	1.2	<0.5	<0.6	14
36	E	NP	M	4.55	1460	1	<0.6	<0.60	<0.4	1.1	2.1	<0.6	13

[1]AG =Arctic grayling, NP = northern pike.
[2] K = kidney, L = liver, M = muscle.
[3] Higher LODs for these samples are the result of low sample weight.

APPENDIX N: TOTAL LENGTH, FORK LENGTH, WEIGHT, AND GENDER OF FISH CAPTURED FOR TISSUE METALS ANALYSIS AT INNOKO NATIONAL WILDLIFE REFUGE, ALASKA, 1997.

Site	Rep.	Species[1]	Total Length (mm)	Fork Length (mm)	Weight (g)	Gender
Tolstoi	A	AG	400	380		
Tolstoi	B	AG	390	360	466	M
Tolstoi	C	AG	390	360		
Tolstoi	D	AG	370	355	462	
Tolstoi	E	AG	400	370	530	M
Innoko R.	A	NP	580	560	1106	M
Finland	A	AG	325	300	278	M
Scand.	A	AG	320	300	270	
Dishna R.	A	NP	610	570	1410	M
Big Mud	A	NP	560	530	1094	F
Iditarod R.	A	NP	550	540	1010	
1st Chance	A	NP	580	560	1158	F
1st Chance	B	NP	540	520	1124	M
Pike Hole	A	NP	940	920	6200	M
Pike Hole	B	NP	960	910		F
Pike Hole	C	NP	970	950	6200	M
Pike Hole	D	NP	920	890	4050	M
Pike Hole	E	NP	870	840	3900	M

[1]AG =Arctic grayling (*Thymallus arcticus*), NP = northern pike (*Esox lucius*).

APPENDIX O: HISTOLOGICAL ANALYSES OF JUVENILE COHO SALMON

Histological analyses of selected tissues of juvenile coho salmon *(Oncorhynchus kisutch*) from Illinois Creek were performed by U.S. Fish and Wildlife Service, Fish Technology Center, Bozeman, Montana.

Silver salmon from Illinois Creek, Alaska, and Dolly Varden (*Salvelinus malma*) from Evaingiknuk and Red Dog creeks were received as preserved specimens. Gill, heart, kidney, liver, pyloric caeca/stomach, intestine, and gonad tissues were dissected and prOcessed by standard histological technique. Sections were stained with hematoxylin-eosin or Giemsa and examined 63x-100x on a Zeiss microscope. Sections were read blind , i.e., without knowledge of group or site of collection. Cellular changes were rated on a scale of 1-5: minimal (1), mild (2), moderate (3), moderately-severe (4), and severe (5).

Coho Salmon - Illinois Creek

Twenty fish were examined.

Gill - overall good condition; mild to moderate thickening of gill epithelium on 18 fish; 2 of the 18 also showed moderate fusion of lamellae.

Heart - mostly normal; one fish showed focal, mild degenerative changes in cardiac muscle.

Kidney - myxosporean parasite, *Myxidium* sp., in kidney tubules of 13 fish; no lesions associated with infection. Hylaine droplet degeneration tubule epithelium seen in two fish; one mild, one moderately-severe. Mild to moderate proliferation of hematopoietic tissue seen in 8 fish and moderate accumulations of melanomacrophages in 3 fish.

Liver - no degenerative or necrotic changes seen in hepatocytes. Glycogen vacuolation was mostly mild (6) or moderate (7); the remaining showed minimal or no glycogen in hepatocytes. Small lympocytic foci were noted in 9 fish.

GI - normal; rodlet cells abundant in the mucosal epithelium of the intestine in two fish.

Gonad - normal in 4 fish with ovarian tissue.

Summary: Overall, histological examination showed these fish to be in good condition. Glycogen vacuolation of hepatocytes is related to feeding activity. Livers with little or no glycogen vacuolation suggest that the fish has not been feeding and has utilized the stored glycogen. Infection with the myxosporean parasite, *Myxidium* sp. did not induce pathological lesions or a host response. Non-pathogenic myxosporean parasites are increasingly being used as biological tags in anadromous salmon.